Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 196 OCTOBER, 1923 No. 4

ENGINEERING PROBLEMS SOLVED BY PHOTO-ELASTIC METHODS.*

BY

PROFESSOR E. G. COKER, M.A., D.Sc., F.R.S.

University College, London.

TWO LECTURES DELIVERED AT THE ROYAL INSTITUTION OF GREAT BRITAIN, MAY 17 AND 24, 1923.

LECTURE I.

(a) IMPROVEMENTS IN APPARATUS.

(b) CONTACT PRESSURES AND STRESSES.

In some former lectures which I had the honor to give at The Royal Institution in 1912, a brief survey was attempted of the application of polarized light to engineering problems of stress distribution, and incidentally a few essential facts were described which are necessary for grappling with problems of stress distribution by this form of experimental investigation. It will, therefore, not be necessary on this occasion to devote time to these considerations and it seems more appropriate to describe one or more fields of investigation which have been pursued during the intervening years, and it is this course which it is proposed to follow here.

Everyone who has carried out experimental work is well aware that, in general, a great deal of time must be devoted to devising and constructing new apparatus or improving existing forms in order to attack problems which have not been attempted before, or if attempted are only partially solved, and it frequently happens

* Communicated by Prof. E. G. Coker, Associate Editor of this JOURNAL.

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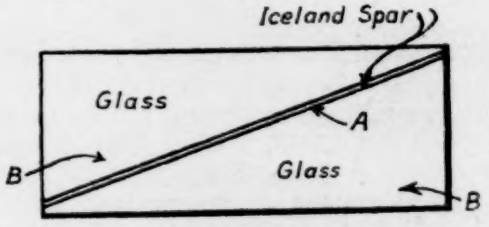
that much more time is spent in this way than the investigation itself ultimately takes. The design and construction of measuring instruments of precision is in fact a branch of experimental research, which is nearly always a prominent feature in any physical investigation, and especially so in engineering science. It will not, therefore, be a waste of time to give an account of some useful improvements in apparatus which have been devised for photo-elastic research during the last few years.

Polarized Light.—A fundamental requirement in this subject is a beam of plane or circularly polarized light of sufficient purity and intensity to reveal the state of stress in loaded models of a machine or structural element constructed from a transparent

FIG. 1.



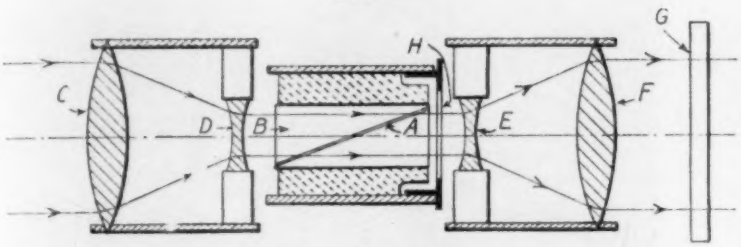
Polarizing prism.

material. An Iceland spar prism cut in the manner invented by Nicol, or in other modified ways devised since, is by far the most perfect means of obtaining the kind of light required. Even the best alternatives, so far as I am aware, are much inferior in polarizing effect, but the scarcity of suitable spar is so great that suitable large prisms constructed wholly of this rare mineral are rarely obtainable, and much ingenuity has been devoted to overcoming this difficulty. Among the many which have been suggested, one may be mentioned which appears to be especially valuable, since it reduces the amount of spar to a minimum. It is in fact found that a very thin plate of spar *A* (Fig. 1) suitably cut in relation to the crystallographic axes and mounted between glass wedges *B* is almost, if not quite, as efficient a polarizing medium as the all-spar prism devised by Nicol and the numerous variants of it suggested since. It is even possible to build up such a plate from small elements cut and mounted in precisely the same manner so as to form a larger plate little if any inferior to a single one cut from a much larger crystal.

One of the great difficulties in this kind of work appears therefore to be solved, but so far only small prisms appear to have been constructed in this way, and the beam of light from it has to be enlarged by the addition of lenses which serve to contract the somewhat large beam to a suitable size to pass through this polarizing prism and afterwards to expand it to a suitable size on emergence.

A simple way of carrying this out, devised by Mr. A. L. Kimball and myself, is shown in Fig. 2 in which a beam of ordinary light passes through a double convex lens *C* and the cone of rays formed in this manner is rendered parallel by a double concave lens *D* to pass through the polarizer. The beam

FIG. 2.



Arrangement of polarizer and analyzer.

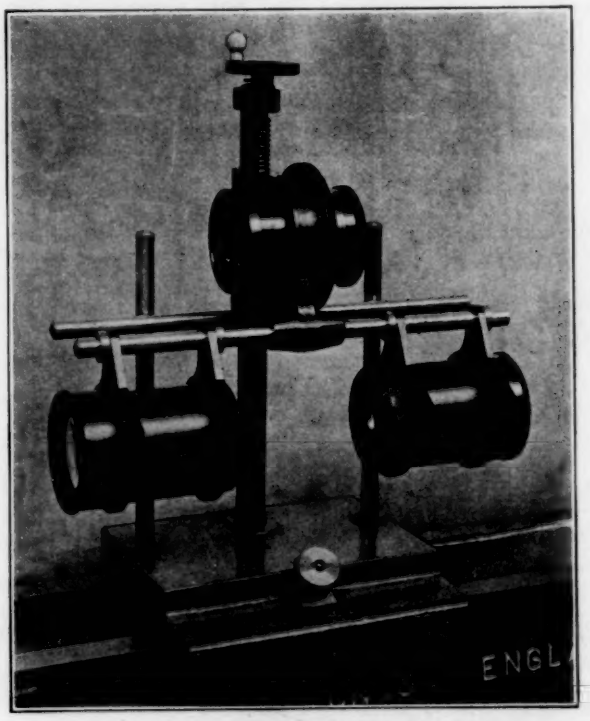
is afterwards expanded by an inverse arrangement of lenses *E*, *F* to the required size for observing the condition of the transparent model *G*.

The interposition of a quarter-wave plate of mica *H* may be used to convert this plane polarized beam into a circularly polarized beam when required.

The form which this arrangement has taken in the most recent designs is shown in the accompanying photograph of a polarizer (Fig. 3), with the cases containing the lenses for obtaining a conical beam turned down in order to show the arrangement of the central prism and quarter-wave plate more clearly. In use, however, these lenses are set correctly with respect to the optical axis, as shown in the second photograph (Fig. 4). Both central prism and quarter-wave plate are mounted in suitable casings, so that each can be turned round through any angle quite independently of the other, and set by cylindrical scales indicated in the photograph. Each part can be readily removed when the

lens systems are turned over as described above. The frame carrying this prism and the lens system is also capable of adjustment vertically by a screw, and a horizontal adjustment for bringing the optical axis in line with other lenses is secured by a screw which pulls the base casting into contact with the ver-

Fig. 3.

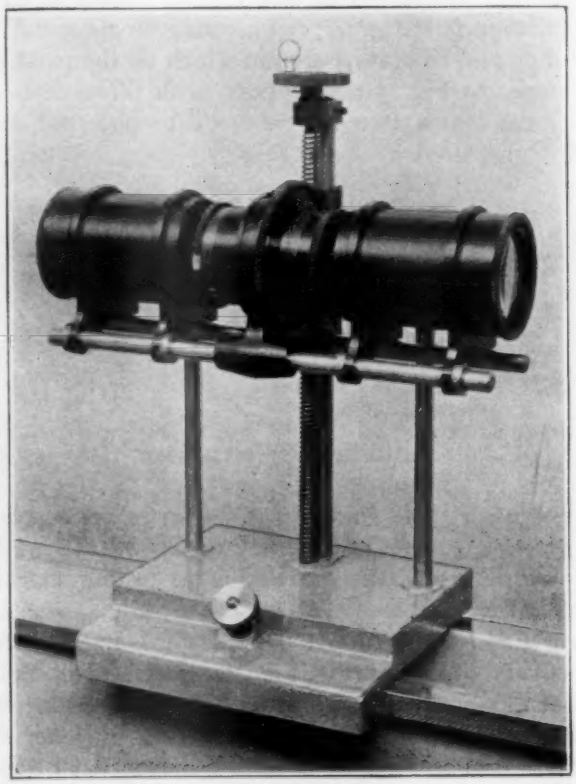


Polarizing prism with the converging and diverging lens systems lowered.

tical face of a lathe bed on which all the required pieces are mounted. Although there are some interesting kinematic details in this arrangement, it will not be necessary to describe these here, as they are clearly shown in the photograph. In general the polarizing prism requires to be set in position in relation to several other optical and mechanical devices, and usually so that the stress effects in the model under examination can be compared with those observed in a loaded tension member by projecting both

on to a screen or else photographing one or both on a color plate. The most convenient way is, therefore, to provide such an arrangement of lenses that both model and tension member can set in separate parallel fields and be projected clearly on to the same plane. A method of doing this, suggested to me by Pro-

FIG. 4.



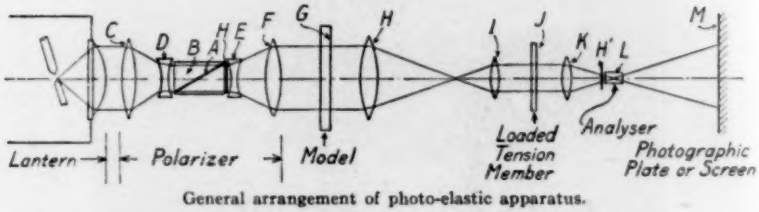
Polarizing prism mounted and ready for use.

fessor Filon, is shown in Fig. 5, in which the parallel beam emerging from the polarizer passes through the model G and is then reduced in size by a lens H and later brought to parallelism by a second lens I to allow observations on the comparator bar J. After passing through this the beam is brought to a conical pencil by a lens K in order to pass through the quarter-wave plate H' and analyzer L and is finally received either on the screen M,

or else a photographic plate if permanent records are required. This optical scheme gives all the flexibility required for experiment and gives a much better result than any scheme in which both objects have to be set in the same parallel field, since in such an arrangement it is usually difficult to get clear images of both bodies and one is necessarily somewhat out of focus.

A complete installation of this type is shown in the accompanying photograph (Fig. 6), representing an apparatus designed for workshop and laboratory use, in which all the parts described with reference to Fig. 5 now appear, with the exception of the model and the comparator bar. As will be observed, each piece is adjustably secured by a suitable grip to a vertical standard,

FIG. 5.



General arrangement of photo-elastic apparatus.

while the horizontal adjusting screws of the bases serve to grip each member to the bed, and also to give each part the requisite horizontal adjustment. In addition the bases are so constructed that they can be used on an ordinary table, so as to facilitate the assembly of the apparatus in relation to testing machines and models of large size.

Lateral Extensometer.—At a Friday evening Discourse [1] in 1916, methods of measuring the stress effects observed in a transparent model were described by comparing them with those observed in a simple tension or compression member cut from the same material and loaded in such a manner that the stress t_1 in it just balances the principal stress components p and q at a point in the model. We have in all such cases

$$t_1 = p - q$$

but this measurement is not in general sufficient, as we usually desire to know p and q separately. This further knowledge can also be obtained by purely optical means [2] or, if preferred, by

[1] Appendix (21).
[2] Appendix (18).

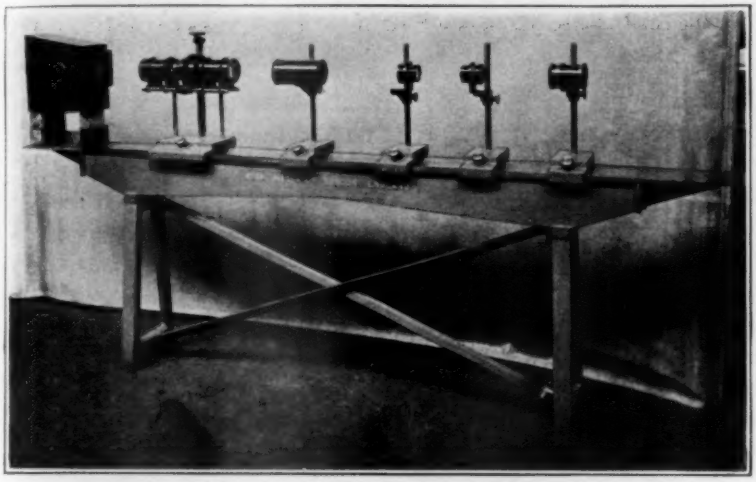
measuring the change in the thickness at the same point and comparing it with the lateral changes in a simple member under tension or compression. For equality we have

$$t_3 = p + q$$

and this relation is easily found.

An instrument for measuring these lateral changes was described at the time, itself an improvement on earlier models, but a great many minor features have been added since which

FIG. 6.

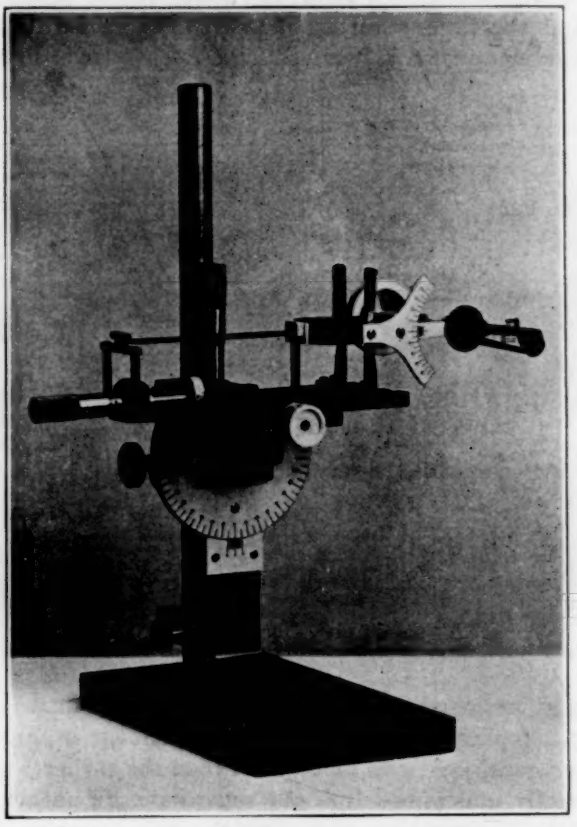


Apparatus for photo-elastic experiments designed for use in engineering workshops and laboratories.

have largely increased its usefulness, and as now made it is the somewhat complicated looking instrument shown in Fig. 7. It is, however, much easier to manipulate than the earlier forms. It will be readily understood that one must have the means of setting the lateral extensometer so that the measuring needles can be brought to any place on the model, and to effect this the supporting framing is now mounted to slide on the single vertical pillar shown, under the control of a micrometer screw which appears immediately in front of the pillar, and which bears against a second block also itself capable of sliding on the same pillar, but usually fixed thereto by a friction grip. In some cases it may be desirable to move the instrument vertically a slight amount

without touching the micrometer screw, and to effect this a second micrometer screw of small pitch is interposed, in series with the micrometer screw, which can be turned round to effect slight adjustments. This enables an operator to start a set of

Fig. 7.



Lateral extensometer.

observations in a given plane with the vertical micrometer at an initial zero reading, an obvious advantage.

The arrangement is in fact equivalent to having two micrometers in line, only one of which is used for measurement. In addition provision is made for the introduction of end measure standard blocks, so that the range of the micrometer can be

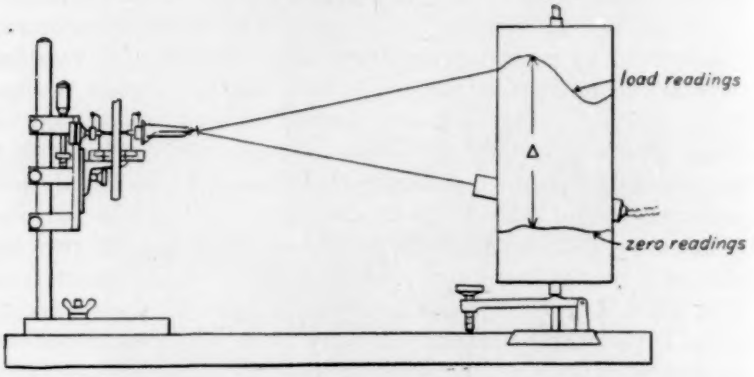
extended from say one inch to several inches. Finally the central reference block forms one element of a simple sliding pair with the main frame, and this latter can therefore be secured in such a position that a vertical plane through the main pillar has any required azimuthal angle. This arrangement dispenses with a second pillar used in earlier forms. The main cross slide carrying the extensometer has somewhat similar arrangements, but in addition it is itself mounted on a transverse slide controlled by a micrometer screw, seen in the foreground, so that a slight adjustment can be given to bring the extensometer into such a position that the axis of its tail-rod is in the central plane of the main slide.

As will be observed, the horse-shoe frame of the extensometer is supported by a three-point suspension consisting of two fine wires at the front ends and a spherical ball bearing on the end of the tail-rod. This allows a certain amount of freedom to swing, which it is found desirable to have, but carries with it the possibility that the measuring needles may not be exactly perpendicular to the sides of the model. This is, however, ensured by the cross-slide screw mentioned above, and also by two fine lines, one on the extensometer and another on the main cross slide, which lie end-on to one another when the setting is correctly made. It sometimes happens that a line along which measurements are desired is neither horizontal nor vertical, and it is convenient, therefore, to mount the main cross slide on a horizontal axis so that it can be set to any desired inclination by a graduated circle and vernier plate on the main vertical slide. This inclined arrangement causes the spot of light reflected from the mirror of the extensometer to move at an angle to the vertical. This is inconvenient for reasons which will appear immediately. In order to so arrange the instrument that the spot of light shall always move in a vertical plane, the casing containing the multiplying gear of the extensometer is arranged to turn round the axis of the contact needles and it is set at the required angle by a graduated scale and vernier plate mounted on the horse-shoe frame of the extensometer, as shown on the right-hand side of the photograph. This latter scale and the one attached to the main cross slide are both graduated so that when both are in correct adjustment the readings are the same.

With these arrangements the lateral changes at points a few thousandths of an inch apart can be measured with comparative

ease, and in fact it was soon found that the principal difficulty lay in the fact that the time required to analyze several hundred such observations in a laboratory notebook was excessive, and the more so that at least two different observations are required at each point because the parallel surfaces touched by the needles are never flats in the optical sense; they are usually in such a condition that the natural variation of thickness from one point to another is of the same order as the changes produced by stress. In order therefore to get an orderly arrangement so that measure-

FIG. 8.



Arrangement of lateral extensometer and drum recorder.

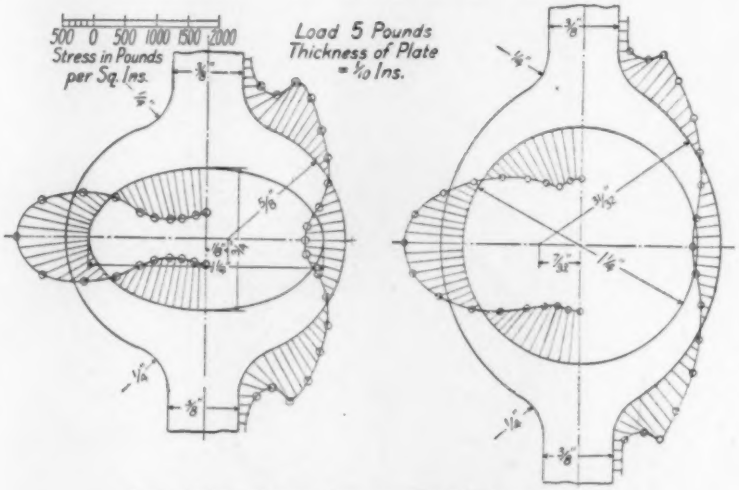
ments of each and every observer could be readily analyzed, the plan was adopted of plotting each observation directly on a large sheet of squared paper wrapped round a cylindrical barrel (Fig. 8) pivoted on a vertical axis. The movement of the spot of light due to the natural variation of thickness along any line of the specimen is taken as a base line from which the observations of the change due to stress can be measured and the corrections required for angularity of the beam of light and the like can be drawn in with paper templates. The final results are thus obtained without any arithmetical calculations and are usually all on the same sheet. As a matter of detail it may be interesting to mention that it is found convenient to reduce the stress measurements so that they refer to a standard thickness of material whereby two independent investigations by different observers can be compared.

As will be noticed in the photograph, the drum of the recorder

can be raised or lowered to bring the zero reading of the extensometer to a definite position on the paper, and when a large model is under examination it is mounted on a transverse slide and is moved by hand to follow the horizontal movement of the extensometer.

The arrangement could obviously be easily made autographic by a mechanical gear connecting the rotating drum and the

FIG. 9.



Stress distributions at the contours of ring-shaped springs.

micrometer slides and using photographic paper, but so far this has not been found necessary.

Spring Balances for Use in Experiments on Transparent Models.—A minor difficulty which often presents itself in examining the stress distribution in a model is to load it properly in a convenient and easy manner. Probably nothing is better than a dead weight if it can be used, and this is generally possible for experiment on the effects of bending, but becomes highly inconvenient and sometimes impracticable when tension, compression and shearing forces are applied, since the range of stress for which the simple optical law holds,[3] is generally large and is, for example, about 3500 pounds per square inch for nitro-cellulose. The manipulation of the heavy loads required for such stress is

[3] Appendix (26).

therefore usually difficult. Much can be accomplished, however, with a minute form of testing machine of a single or compound lever type, in which the load is applied by a straight pull spring balance with a very open scale suitably calibrated.

Such a case presents itself when employing a loaded tension member for comparison with the stresses observed in a model,

FIG. 10.

Spring balance, face view.

and a useful arrangement of this kind is a very small double lever testing machine mounted on a graduated disc and having a central hole to permit the passage of a beam of light. The disc is adjusted on a vertical rod by a suitable clamp, it has a horizontal cross slide in the base and can be turned round the optical axis of the polarized beam by aid of a fitting at the back of the

disc. With these three adjustments the tension member can be brought into any required position in the field of view.

Even this device, however, may be inconvenient for some kinds of measurement, and spring balances of very small size would often be preferable, but in general these latter are

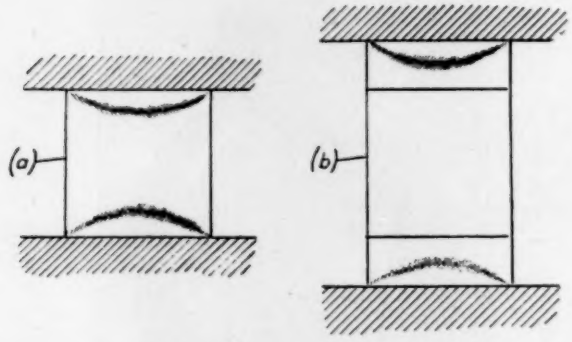
FIG. 11.

Spring balance, back view showing mechanism.

much too bulky for the average loads, required of from 200 to 500 pounds. It has, in fact, been found necessary to devise an alternative form, and the essential feature made use of is the change of form produced in a solid metal spring made preferably in a ring-shaped form in such a fashion that within the elastic limit of any part of it a sufficient change of length in some direction is produced which can be magnified to operate

a dial indicator. In order to obtain a suitable form of spring it is possible to make use of experiments on transparent models to find a shape such that the stress distribution shall not be so excessive anywhere that the limits of elasticity are overpassed. Some of the models of these springs under load are now projected on the screen by aid of a beam of polarized light, and it is possible at a glance to form a good idea of the characteristic features of the stress distribution since the minor principal stresses in most cases are not sufficiently great to affect the color

FIG. 12.



(*a*) Transparent block under normal load between the plates of a testing machine. (*b*) The same block when stressed by aid of intermediate blocks of the same material and of the same cross-section.

effects very much, and a simple color scale enables one to estimate the stresses produced fairly accurately. Two of the forms examined are also shown in Fig. 9 and the stresses found at their contours are indicated thereon. Having chosen in this manner the most suitable spring form it is only necessary to magnify the extension in a steel counterpart in some suitable direction, say along the line of pull or transversely to this line by a suitable mechanical device free from zero errors. After some trouble this condition has been satisfied, and several spring balances constructed in this manner and about the size of a rather large watch have been made and are found to work in a satisfactory manner. In the example shown in the photographs (Figs. 10 and 11) a spring balance is depicted having a dial of two inches' diameter and weighing four and one-quarter ounces, which measures loads up to 240 pounds. It would have been just as easy to make this

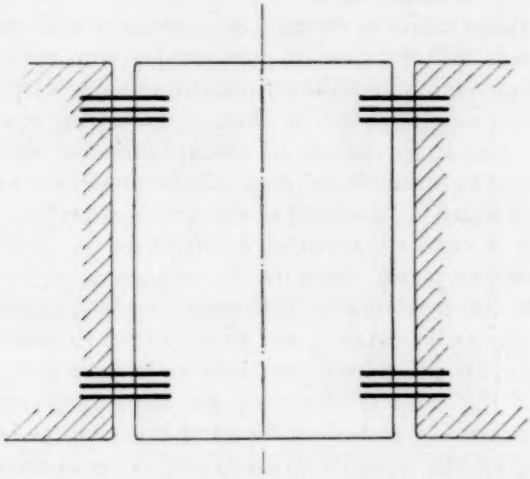
spring measure loads up to a ton or possibly in the other direction to weigh a letter, without alteration in size other than that required by the proportions of the spring itself. A further advantage of this form, other than that of mere reduction in size, is that the energy stored in the balance is so small that, should the model break, the release of this energy in the spring itself is insufficient to cause any damage to the apparatus employed, or to the balance itself due to the sudden return of the index and its attached mechanism to zero position.

It is perhaps useful to mention in connection with the measurement of loads that the case of pure compression requires special consideration, as it is exceedingly difficult to apply correctly owing to the defective construction of most of the testing machines now in use, and also to the effects of contact pressure between materials differing in physical and dimensional properties as described in an earlier paper.[4] In regard to the latter properties, it is found that if say a cube of material is subjected to stress between parallel pressure plates, there is, in general, a region of stress at each end due partly to the difference in physical properties of the two materials in contact, and partly to the dimensions of the surfaces, so that the central part only is in pure compression as indicated in Fig. 12. If, however, the block is pressed between plates of the same size and of the same material, as indicated in the same figure, the local disturbances only occur in the end blocks, and the central one is then under approximately pure compression stress. The mechanical difficulty of keeping the compression plates parallel, and yet so arranged that the total load applied shall be measurable, is considerable. It is most effectively solved in the well-known Emery testing machine, but for the small compression machines needed in photo-elastic investigations it is convenient to use a form of apparatus[5] which has been in use for a number of years in my laboratory, consisting of a long cylindrical plunger (Fig. 13) secured in the main frame of the machine by thin concentric diaphragm plates at each end, so as to allow a very small displacement axially by the elastic deformations of the annular diaphragm. The load on the lower plate can be applied in any convenient fashion provided the two pressure plates are kept exactly parallel, and the applied force P at

[4] Appendix (30).
[5] Appendix (11).

the top plate attached to the plunger is conveniently measured by a single lever connected to the plunger by a thin spring plate and pivoted on a second spring plate in a similar manner to those used in the Emery testing machine. The use of spring plates and guiding diaphragms adjusted to unstrained positions instead of combinations of knife edges has the additional advantage that any energy stored in them by their change of shape is restored when

FIG. 13.



Plunger secured by diaphragms and having a limited movement axially.

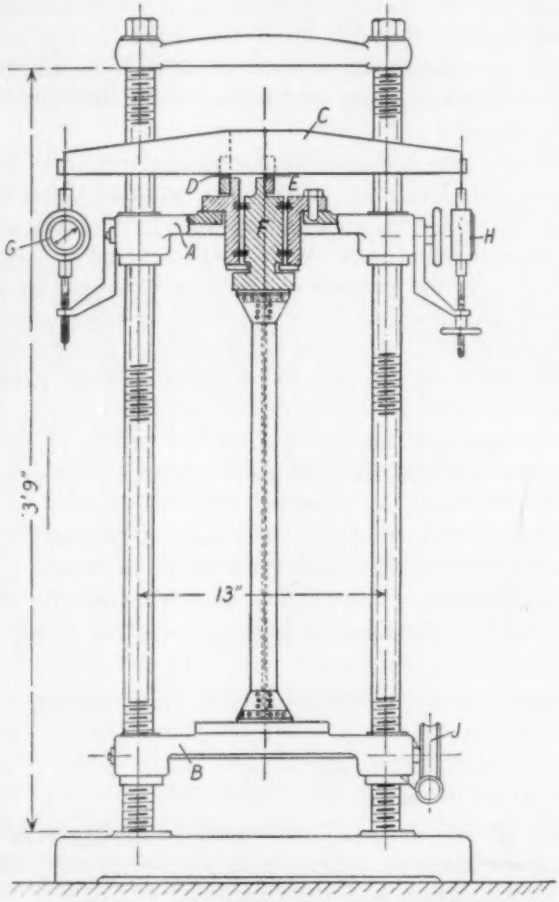
this equilibrium position is gained and is also available to help restoration, whereas any frictional effect is irreversible.

The applied force can be measured at the end of the lever by dead weights, or, if too large, by a small spring balance as indicated here. Such a machine on a larger scale is of use for models of considerable size; one of this type was constructed about two years ago for the General Electric Company of America, in which the detail features were designed in collaboration with their representative, Mr. A. L. Kimball, Mr. F. H. Withycombe and Mr. Macklow Smith. This machine was also capable of applying both tension and compression loads. In a larger testing machine now under construction at University College the same general arrangement is being used and is represented by a diagram (Fig. 14) in which it will be noted that both the upper head *A* carrying the measuring apparatus and the lower head *B*

for applying load are carried on screwed standards by nuts connected by worm-gear drives, so that each head can be traversed by gearing to any required position.

The main lever *C* for weighing the load is supported on a steel

FIG. 14.



Testing machine for large transparent models.

plate knife edge *D* so designed by photo-elastic methods that the tendency to buckle under the direct thrust upon it is reduced to a minimum, thereby removing a difficulty experienced in earlier forms. The ends of this plate are also constructed to provide ample bearing surfaces at the points of connection to the casing

and the main lever so that no slip can take place between them. The steel plate E for the plunger F is of the same form, and each end of the lever is also provided with similar steel plates to carry dead weights or, when heavy loads are necessary, spring balances G and H of the forms described above.

An experimental column is shown in position in this machine under load applied through the lower head by the worm gear J and weighed by the spring balance H, while the spring balance G is prevented from exerting any influence by the removal of the nut on the screwed extension.

The Connection between the Stress Distribution Observed in Transparent Models and Those in Actual Structures and Machines.—It is natural to enquire how far one may rely on the stresses observed in plate models constructed of transparent materials to infer the stresses in the actual element of a machine or structure, and this has been subjected to rigid scrutiny from every possible aspect. It can be shown that in general the identity is complete, but it would take too long to give the evidence here which may be found in several papers by my colleague, Professor Filon, Mesnager and myself, and which prove, if the laws of similarity are observed, that the stress systems produced in bodies of different materials are precisely the same within the limits of elasticity of each material when the body is enclosed by a single boundary, or in which the loads on separate boundaries are themselves in equilibrium. There is a theoretical reason for this, which may be found in treatises on elasticity, but is worth referring to here.

The stress strain equations for a plate loaded in its own plane are

$$\frac{\partial \widehat{xx}}{\partial x} + \frac{\partial \widehat{xy}}{\partial y} = \frac{\partial \widehat{xy}}{\partial x} + \frac{\partial \widehat{yy}}{\partial y} = 0 \qquad (1)$$

leaving out as non-essential the terms involving volume forces and for these equations, and we have a solution for these stresses in terms of a function χ in the form

$$\widehat{xx} = \frac{\partial^2 \chi}{\partial y^2}, \ \widehat{yy} = \frac{\partial^2 \chi}{\partial x^2}, \ \widehat{xy} = -\frac{\partial^2 \chi}{\partial x . \partial y} \qquad (2)$$

while the strain relations are readily shown to be

$$\frac{\partial^2 \varepsilon_{xx}}{\partial y^2} + \frac{\partial^2 \varepsilon_{yy}}{\partial x^2} - \frac{\partial^2 \varepsilon_{xy}}{\partial x . \partial y} = 0 \qquad (3)$$

The equations connecting the strains and stresses have the form

$$\left.\begin{aligned} mE\varepsilon_{xx} &= m.\widehat{xx} - \widehat{yy} \\ mE\varepsilon_{yy} &= m.\widehat{yy} - \widehat{xx} \\ mE\varepsilon_{zz} &= -(\widehat{xx} + \widehat{yy}) \\ mE\varepsilon_{xy} &= 2(m+1)\widehat{xy} \end{aligned}\right\} \quad (4)$$

and it is easily possible with these relations to express the fundamental equation of plane stress in terms of χ only in the form

$$\frac{\partial^4\chi}{\partial x^4} + \frac{\partial^4\chi}{\partial y^4} + 2\frac{\partial^4\chi}{\partial x^2.\partial y^2} = 0 \quad (5)$$

which, as will be noted, contains no elastic constants and hence the stresses which are all derived from χ cannot depend on such constants.

We have therefore, apart from experiment, conclusive evidence on theoretical grounds that experiments on transparent models do actually inform us what are the stresses in materials used by engineers. If it were possible to solve the last equation $\nabla^4\chi = 0$ in an absolutely general fashion, we should be able to find by calculation the stress in any plate-formed body under any loading in its own plane, but it seems unlikely that such a general solution will be found, and even if it were it is more than probable that its complexity would be an insuperable bar to its use in most of the cases which occur in practice.

Although a further matter does not arise in the researches described here, I must not omit to mention, however briefly, the important question of the stress distribution in multiply-connected bodies like that of a solid connecting rod, let us say, in which the loads on the internal boundaries do not balance separately and independently of one another. In that case the fundamental stress equation is not free from elastic constants, and photo-elastic experiments require a correction to fit them for use in other cases where the material is of a different nature, but the recent researches of Filon [6] show that, in the majority of cases, this correction is within the error of experiment, and that in any case its value may be determined by experiments.

[6] "On Stresses in Multiply-connected Plates," Prof. Filon, F.R.S., British Association Report, 1922.

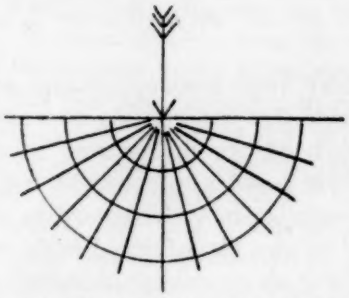
CONTACT PRESSURES AND STRESSES.

(*a*) *Point Contact.*—An important field of work in which photo-elastic investigation can be of considerable service is that of the distribution of contact pressures between plane and curved surfaces of which there are any number of examples of practical importance in engineering work. The simplest possible case is that in which we have a concentrated load P applied perpendicularly to the straight edge of a semi-infinite plate for which

$$\chi = \frac{P}{\pi} \widehat{r\theta} \sin\theta \tag{6}$$

is a solution of equation 5, which satisfies all the conditions of

FIG. 15.



Lines of principal stress due to normal point loading at the edge of a thin plate.

the problem, and gives a stress system found from equations (2), expressed in polar coördinates and defined by

$$\widehat{rr} = \frac{2P}{\pi} \cdot \frac{\cos\theta}{r}, \quad \widehat{\theta\theta} = \widehat{r\theta} = 0 \tag{7}$$

or the stress in the plate radiates in all directions from the point of application of the load, and diminishes linearly with the distance, and also varies with the obliquity of the direction according to a cosine law. The lines of principal stress all meet at the point of application of the load, and the corresponding orthogonal system consists of circles struck from the point of application as centre, as shown in Fig. 15, but it will be noted that these latter are lines of zero principal stress since $\widehat{\theta\theta} = 0$. Optically this stress system is represented by color bands in the form of complete circles touching the boundary at the point of application, and with centres on the line of load for here

$$p - q = \widehat{rr} - \widehat{\theta\theta} = \frac{2P}{\pi} \cdot \frac{\cos\theta}{r} = A \tag{8}$$

where the magnitude of A depends on the order of the color band. Now for any definite value A, we have for a distance R_0 immediately below the point of application

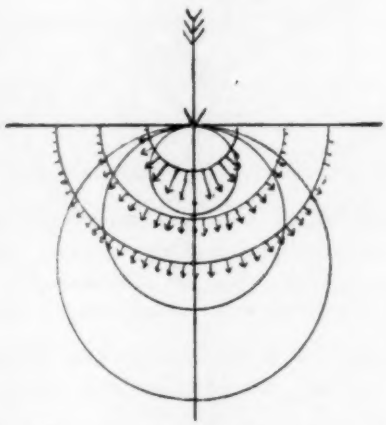
$$\frac{2P}{\pi} \cdot \frac{1}{R_0} = A$$

so that

$$r = R_0 \cdot \cos\theta \cdot \tag{9}$$

Some of the circles corresponding to this last equation are

FIG. 16.



Stress distribution due to normal point loading at the edge of a thin plate.

shown on Fig. 16, while the stress systems across the circles of principal stress are also indicated.

This distribution was approximately verified by Carus-Wilson [7] and has also been examined by Mesnager.[8] It is important to note that if the concentrated load is applied at a point well inside a very extended plate, it would produce all round radial stress of the same type with two systems of color bands in the form of circles having centres along the line of loading and passing through its point of application, as indicated in Fig. 17,

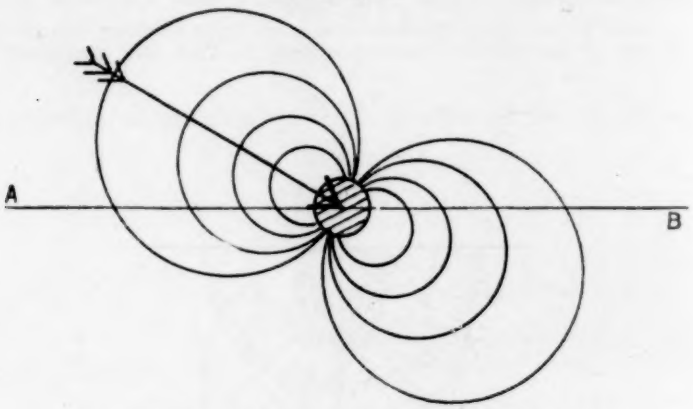
[7] "The Influence of Surface Loading in the Flexure of Beams," Prof. C. A. Carus-Wilson, *Phil. Mag.*, Dec., 1891. See also Appendix (30).

[8] "Utilization de la double réfraction accidentelle du Verne a l'étude des efforts intérieurs dans les solides," M. A. Mesnager, Association Internationale pour l'essai des Matériatix. VIe. Congres New York, 1912.

and it is possible to show this experimentally by gripping a plate of nitro-cellulose over a very small area and exerting a tangential stress upon this latter as you now see in the polariscope.

In practice, concentration of load is never quite so perfect as the simple theory assumes, and there is always a distribution over

FIG. 17.



Color band system developed by tangential stress at a point in a plate.

a finite area which, if it is uniform and of intensity p along the straight edge of a plate, can be calculated, since then

$$\chi = \frac{p}{2\pi}(r_1^2 \cdot \theta_1 - r_2^2 \cdot \theta_2) \tag{10}$$

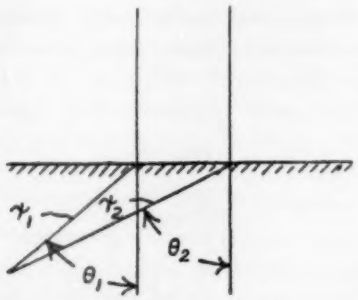
satisfies all the conditions when r_1, θ_1, and r_2, θ_2 are measured from the ends of the block (Fig. 18). We then have a stress system

$$\left.\begin{aligned} \widehat{rr} &= \frac{p}{\pi}(\alpha + \sin\alpha) \\ \widehat{\theta\theta} &= \frac{p}{\pi}(\alpha - \sin\alpha) \\ \widehat{r\theta} &= 0 \end{aligned}\right\}. \tag{11}$$

with reference to an origin at the edge where a vector bisecting the angle $(\theta_1 - \theta_2) = \alpha$ intersects this line. The lines of stress are therefore confocal conics with foci at the ends of the contact area of the small block as Fig. 19 shows. Even with a very large plate, however, this distribution is not obtained exactly, as it seems impossible to distribute a pressure uniformly over a small area

when it forms part of a larger one, for you will notice in the accompanying experiment in which a block one inch square is loaded at the centre of one side by a block $\frac{1}{8}$ inch wide that there is a very complicated stress system caused by non-uniform pres-

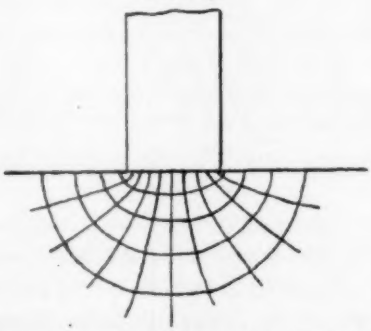
FIG. 18.



Coördinate system for a plate uniformly loaded over part of its edge.

sure at the contacting surfaces with a considerable increase of intensity at the end points. It has in fact been shown [9] that, not only is there non-uniform pressure, but that in general the

FIG. 19.



Lines of principal stress due to normal load uniformly distributed over a small part of the edge of a large plate.

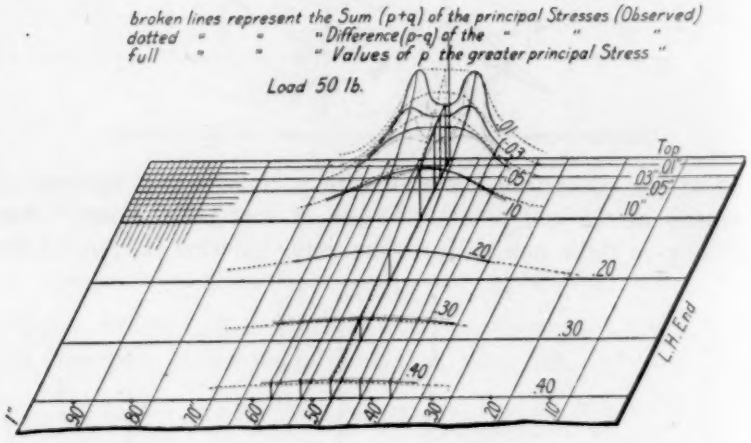
supported lower edge of a very large plate loaded above in this way is also under non-uniform contact pressure, which tends to concentrate about the line of load, while the outer ends tend to rise.

This has also been shown independently by my colleague,

[9] Appendix (30).

Professor Filon,[10] who has proved that in a block of depth b there cannot be contact at the lower edge at distances beyond 1.35 b from the line of a single concentrated load. It is particularly noticeable here how intense the contact pressure is at the ends of the loaded area of the upper face. The stress distribution when measured confirms this and we find, as the semi-perspective view (Fig. 20) shows, that immediately under the centre of the contact area the pressure is least and approaches to a maximum at the end points. Moreover, this type of distribution tends to maintain itself, and only gradually dies away and ultimately

FIG. 20.


broken lines represent the Sum (p+q) of the principal Stresses (Observed)
dotted " " "Difference(p-q) of the " " "
full " " " Values of p the greater principal Stress "
Load 50 lb.
Top
L.H.End

Actual distribution of contact pressures and stresses in a block loaded normally over a small part of its edge.

becomes a non-uniform pressure across horizontal sections with a maximum value at the centre. As we have seen above, even if such a block is loaded over the whole of a pair of opposing faces, we do not find that it is under uniform compression stress if materials of different kinds are in contact, as they almost always are when cubes and rectangular blocks of cement stone, brick and the like are tested to destruction, and in fact it appears impossible to obtain absolutely uniform stress in such cases unless the contacting surfaces are of the same material and the same size.

[10] "On the Approximate Solution for the Bending of a Beam of Rectangular Cross-section under Any System of Load," L. N. G. Filon, *Trans. Royal Soc.*, Series A, Vol. 207.

When we turn to cases of contact stress of curved surfaces, there is a bewildering variety of practical problems which deserve our attention, but I will only refer briefly to one of these, the contact pressures of the teeth of gear wheels, which you now see in action in the polariscope.

You cannot fail to notice that the pressures of these curved surfaces produce systems of color bands of the line contact type, somewhat modified by the curved contours from those of an earlier case, and in addition there are intense stresses caused by the bending action of the applied forces, which latter produce dangerous stresses at the roots of the teeth. Attention was called to this in an early paper [11] and some experiments [12] made by my former research assistant, Dr. Chakko, now Professor of Engineering in the University of Madras, show, in the case of a solid spur wheel, the lines of principal stress in the tooth, one example of which is shown in the upper part of Fig. 21. The stress system is a somewhat complicated case of contact stress owing to the form of the curved boundary, at which, as the color bands indicate, the stress attains maximum values. The stress distribution over the boundary of this tooth for this position is shown in the lower part of Fig. 21, and its variation along it indicates how intense is the contact stress and also how very unlikely it is for the usual methods of calculating the stresses in teeth to be correct. More recently stress distributions in electric railway motor pinions [13] have been determined by similar methods. Some further case of contact pressures and stresses produced in piston rings and chain links [14] have also been examined in my laboratory.

LECTURE II.

(a) THE TESTING OF MATERIALS IN TENSION.

(b) THE ACTION OF CUTTING TOOLS.

Some very interesting cases of stress distribution occur in the testing of materials, and it is proposed in the first instance to briefly refer to the chief features of interest which have been

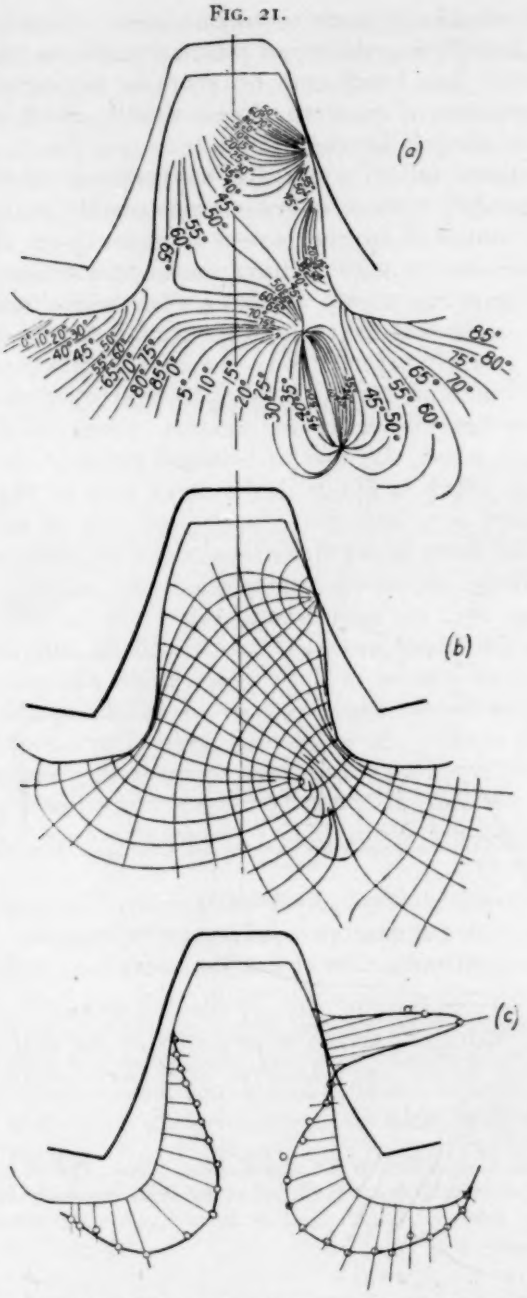
[11] Appendix (4) and (20).

[12] Appendix (36).

[13] "Stress Distribution in Electric Railway Motor Pinions as Determined by the Photo-elastic Method," P. Heymans and A. L. Kimball, *Am. Soc. Mech. Engrs.*, Dec., 1922.

[14] Appendix (35).

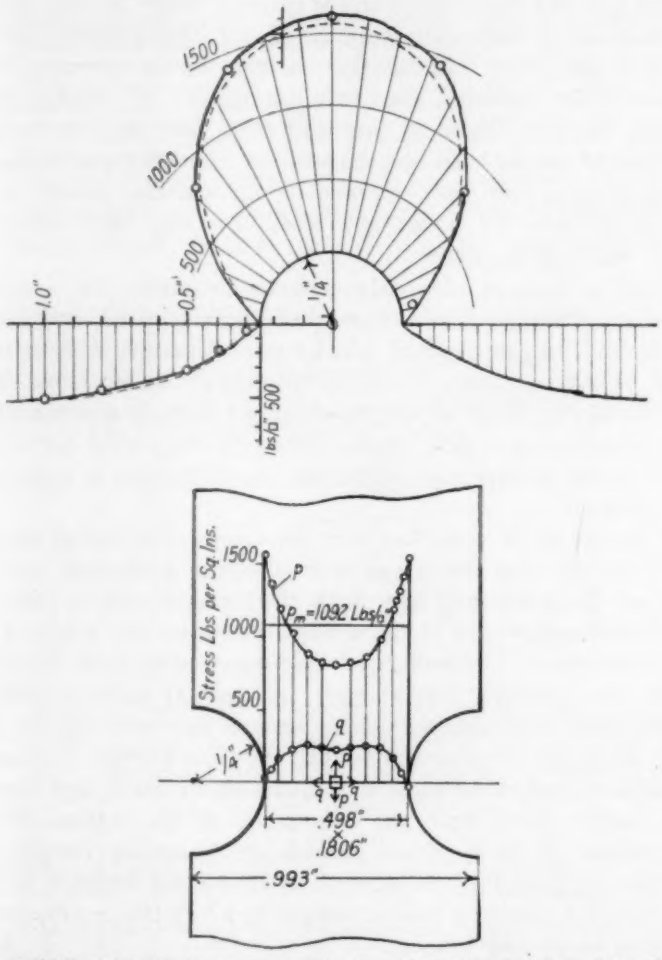
FIG. 21.



(*a*) Isoclinics. (*b*) Lines of principal stress. (*c*) The contour stresses of a tooth of a cog-wheel.

found in some recent investigations [15] on this subject. It will be convenient to start with a primitive form of test piece from which others may be derived, and for this purpose a simple strip

FIG. 22.



Stress distribution in a tension member with symmetrically placed semi-circular notches.

is selected—four units wide having two symmetrically disposed semi-circular notches in it of one unit radius. As you observe when this is loaded in the polariscope, the color picture produced

[15] Appendix (24).

indicates a rather complicated stress system, which extends well into the parallel end portions of the member. At the minimum section there is clearly a very uneven distribution of stress, and measurements of the principal stresses p and q indicate that the axially directed stress varies in the manner shown in Fig. 22 with a maximum at the contours about 92 per cent. greater than the stress at the centre. In addition there is a cross stress q which is zero at the contours, rises to a maximum very rapidly as we proceed towards the axial line and then falls slightly in value towards the centre. Around the semi-circular contours the uneven distribution is still more marked as the extreme points of the semi-circles are not under any stress for any load within the elastic limit of the material.

Such a form is obviously entirely unsuitable for a tension test piece, although it has occasionally been so used, and a more practicable form is obtained when a central parallel strip is introduced of say two units in width, now shown under stress in the polariscope, in which as will be observed there is a non-uniform color distribution which invades this central parallel portion, so that we may be sure that only a part of this latter is under pure axial tension.

It is also to be remarked that the colors observed at the contours indicate that the stress is an absolute maximum near the joint of the quadrantal arcs with the straight central part, and a complete exploration of the whole area shows that this is a correct inference. A number of specimens have been examined which have precisely similar ends, but central parts of different lengths, and measurements have shown that so long as these latter parts are of adequate length, the distribution of stress in the ends is always the same within the elastic limit, and that the zero isoclinic lines form the boundaries of the region of complex stress. It is therefore possible to determine for any test specimen of plate form how much of its central length is in pure tension and to assign a limit of length at which the central portion ceases to be in pure tension.

The effective length in tension for any given contour can be easily determined for any given case, and in Fig. 23 four cases are shown which have been worked out in this way. In these the larger breadth B of the specimen is 0.9316 inch, the smaller breadth b is 0.4600 inch, and the variable factor is the radius

of the fillet joining the ends, as marked in the figure. It will be noticed here that the smaller the radius the greater is the length in pure tension, but this is accompanied by proportionately higher

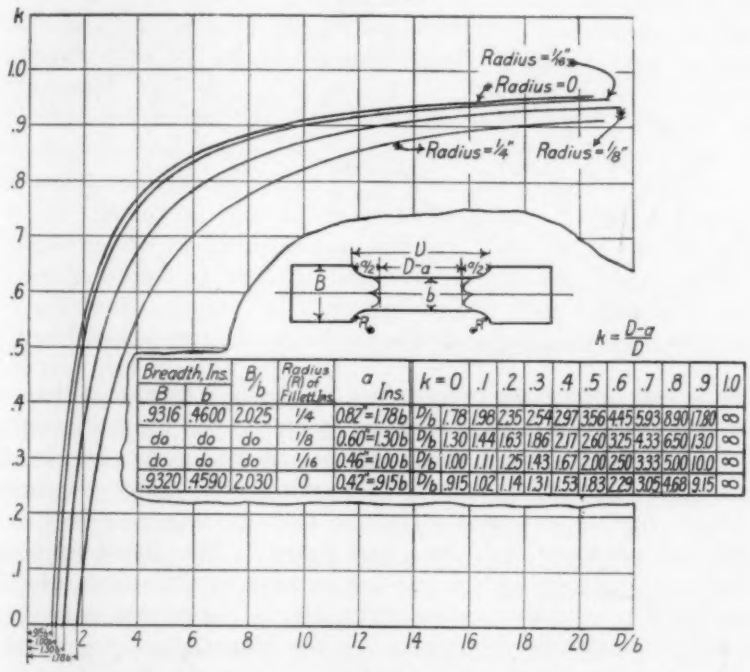
TABLE I.

Tension Specimen of Rectangular Cross-section 0.4600 in. by 0.1812 in. under a Uniform Stress of 1180 pounds per square inch with Enlarged Ends 0.9316 in. wide.

Radius of connecting curve (in.)	1/4	1/8	1/16
Maximum stress in pounds per sq. in.	1480	1725	1890
Percentage increase of stress	23.4	43.8	57.8

stress at the fillet, as is shown in Table I, from which it appears that the maximum stress at the fillet is always appreciably larger

FIG. 23.



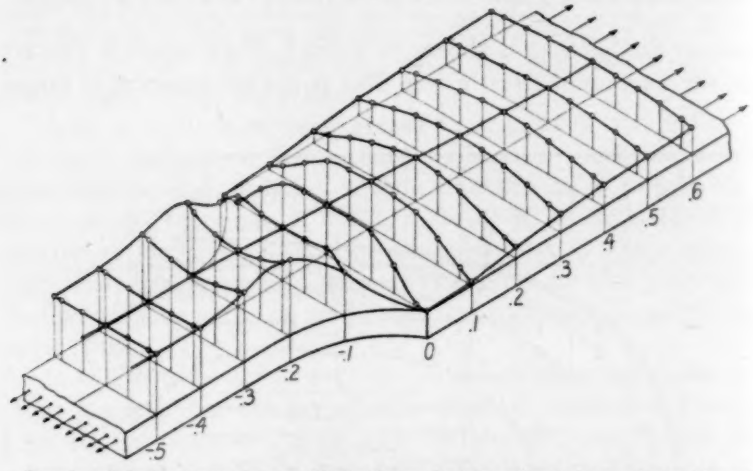
Breadth, Ins. B	Breadth, Ins. b	B/b	Radius (R) of Fillet, Ins.	a Ins.	k = 0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
.9316	.4600	2.025	1/4	0.82"=1.78b	D/b	1.78	1.98	2.35	2.54	2.97	3.56	4.45	5.93	8.90	17.80
do	do	do	1/8	0.60"=1.30b	D/b	1.30	1.44	1.63	1.86	2.17	2.60	3.25	4.33	6.50	13.0
do	do	do	1/16	0.46"=1.00b	D/b	1.00	1.11	1.25	1.43	1.67	2.00	2.50	3.33	5.00	10.0
.9320	.4590	2.030	0	0.42"=.915b	D/b	.915	1.02	1.14	1.31	1.53	1.83	2.29	3.05	4.68	9.15

Fractional part of a test bar in simple tension for various ratios of the length D to the breadth b when the radii at the ends are varied.

than the mean tension and becomes so great with small radii that a brittle specimen tends to break at this section owing to the fact that the elastic stress distribution tends to continue right up

to the breaking point. In a ductile specimen, however, the distribution changes rapidly and tends to equalize after the yield point is passed, as you now observe in the polariscope, and in consequence ductile materials are not so prone to fracture at this section as if the elastic distribution continued. Fig. 24 shows approximately to scale the axial distribution at the ends of one form of tension test bar recommended by the British Standards Committee of The Institution of Civil Engineers,[16] and you will

FIG. 24.



Drawing of the longitudinal stress distribution at the enlarged end of a tension test bar of the British Standards Committee.

notice that one of the peculiarities of the distribution is that in the narrow part the stress tends in general to become a maximum at the edges, while in the wider part the stress tends to a maximum at the centre. Unless, however, the ends are very wide compared with the central portion, it is found in this case that complex stress does not penetrate into the gauge length. The distribution of stress in any other form of tension member of plate form can be measured in a similar fashion and it may be added that in tension members of circular cross-section it has been shown experimentally [17] that complex stress tends to penetrate further into the regions of the gauge length than for the corresponding case of a flat member having the same contour.

[16] Appendix (24).
[17] Appendix (24).

I need hardly point out that the results of these investigations emphasize the danger of relying on tests made on very short specimens, which may be of such a form that it is impossible to produce a pure tensional stress in them by a direct pull.

The Stress Distribution in Cement Briquettes.—Another form of test piece, the cement briquette, is of particular interest and importance to the civil engineer, since the manufacture and use of cement has an international character like steel, and there is no doubt that for both materials the establishment of standard tests of scientific precision, acceptable in all countries, would have a far-reaching effect on trade and commerce between them. Research on this subject has been in progress for some time at University College in order to supplement some earlier work [18] on the same subject, and I take this opportunity of thanking my two research students, Messrs. Anderson and Fukuhara, for their valuable help in making measurements, which I now propose to discuss.

It is at once evident, from what has been described in the last lecture, that the stress distribution in a cement briquette must be of a very complex character. The loads are applied very obliquely to the contour at four points and the shape of the briquette is evidently one which invites complexity. This is at once evident from the lines of principal stress in the British standard form in which the contact loads applied by the grips produce a complicated stress system which would be practically impossible to unravel except by experiment.

At the time of the early experiments in 1913 it was not possible to measure the stress distribution completely, but an attempt was made to find the stress difference $(p - q)$ across the minimum and principal section, and thereby to fix the relation between the maximum stress there and the mean applied load, since at the contour q must be zero at every place untouched by the grips. Some earlier measurements on a British standard briquette indicate that this maximum stress is about 1.75 times the value of the mean average stress across the section, and in the standard American form of that date the corresponding value was found to be 1.70 while in the Continental form it appeared to rise to about 1.95 times the mean stress.

These measurements have been repeated and amplified

[18] Appendix (13).

recently, so that it is now possible to give a better idea of the actual stress systems at the central sections of each form, and Fig. 25 shows the distribution obtained at the minimum sections of each briquette. As will readily be observed the distinctive feature of the distribution in each case is an extremely variable tension p across the minimum cross-section accompanied by a variable cross-stress q at right angles of considerable magnitude. In the British form, for example, with a load giving a mean average stress of 500 pounds per square inch, the highest value of p at the outer contour is 870 pounds per square inch, or 1.74 times the value of the mean stress, which sinks to 405 pounds per square inch at the centre or slightly more than 80 per cent. of the mean average value. In addition to this stress there is a cross stress which rises rapidly from a zero value at the contour to a value of about 235 pounds per square inch for the central six-tenths of the cross-section, so that the manner of loading and the form of the section calls into play a cross stress of 47 per cent. of the mean average stress due to the pull.

We see, therefore, that a member of this form is certainly not in pure tension, and the color bands which are observed on the model indicate this quite clearly.

The standard French briquette shows a much more complicated distribution owing to its different shape and especially to the circular indentations at the waist.

In an actual test of this later form, shown in the figure, a mean average stress of 470 pounds per square inch develops a maximum tensional stress p of approximately 1000 pounds per square inch or 2.13 times the average stress, sinking to a minimum value at the centre of 300 pounds per square inch, that is 64 per cent. of the average value. In other experiments the ratio of the maximum stress p to the average value was found to be 2.05, 2.06 and 2.14, so that it appears very likely that this ratio is in the neighborhood of 2.10 and therefore higher than the earlier value already quoted. The stress system described above is also accompanied by a cross stress, which rises to its highest value near the end of the cross-section and has a slightly less minimum value at the centre of about 260 pounds per square inch or 55 per cent. of the average pull applied and not a great deal less than the tensional pull across the section. We have therefore, as before, a highly complex system of stress at the

cross-section for which the specimen is designed to fracture, as you now see on the screen, and if anything like the same stress system prevails in the actual briquette, we cannot hope to learn anything very definite of the tensile properties of cement under such a complicated system of stresses in it.

It is of interest here to note that French engineers have long been alive to the fact that the distribution across the central section is far from uniform and Durand Claye [19] has proposed an ingenious approximate solution based on some elementary principles, in which he obtains a curve of distribution with pronounced maximum values at the ends of the section.

Having now described the main features of the stress distributions in British, American and French standard briquettes, it is evident that there is a great deal of work still to be done before any practical proposals can be adopted to obtain international uniformity in testing cement.

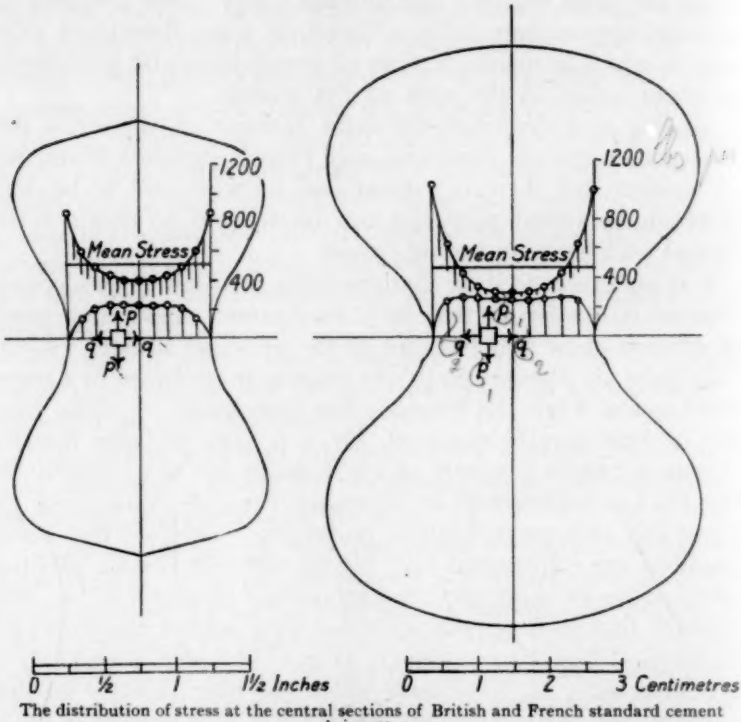
It is important to show that the stress distribution in a cement briquette is similar to that in a transparent model and recent experiments show that the sum of the principal stresses $(p + q)$ at the waist are almost exactly the same as those found in a transparent model when the briquette has been made for some time. This is what may be expected, for it is very probable that the stress in a cement briquette of considerable age is of exactly the same kind as experiments on transparent models show, since old cement has very perfect elastic properties. The fact that sound vibrations are transmitted very readily through cement partition walls and floors show this, and in another direction it has been proved [20] that such cement possesses very perfect thermo-elastic properties. This latter property is not, however, possessed, or only imperfectly so, by cement which has been recently molded, so that so far as this evidence can be taken into account it points to the conclusion that briquettes tested at the end of a week and a month, as is sometimes provided for in standard specifications, will not be under exactly the same type of stress as transparent models show. They are in fact most probably in a semi-elastic condition in which, as all the evidence we possess shows, the stress distribution is less variable than in the purely elastic state,

[19] *Annales des Ponts et Chaussees*, Tome 9, serie 7, June, 1895.

[20] "The Relation of Thermal Change to Tension and Compression Stress," E. G. Coker and C. M. McKergow, *Trans. Royal Soc. of Canada*, 1904.

so that any provisions found necessary from experiments on elastic bodies will more than cover the requirements we seek. The older the briquette the more nearly the stress distribution approximates to that of the elastic condition of the transparent model. The chief bar, however, to uniformity appears to be in the varying shapes of the briquettes themselves, but it does not appear to be

FIG. 25.



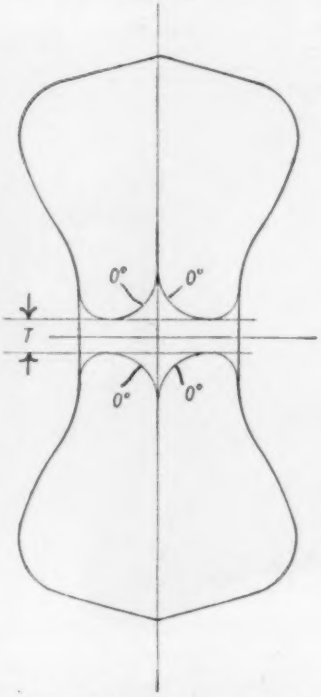
The distribution of stress at the central sections of British and French standard cement briquettes.

impossible to devise a simple means whereby this difficulty can be overcome without the necessity of a wholesale scrapping of existing testing machinery. Briefly, my proposal is to examine how far uniformity of testing can be obtained by maintaining in every case the existing forms of the ends and lengthening the central part by the addition of a parallel part of the least possible length which will satisfy the condition that the stress in that part is a uniform tension. Thus if we take the British standard briquette (Fig. 25) and introduce into it a definite parallel

length, the part in pure tension is at once defined by the zero isoclinics as shown in Fig. 26.

Having established this length T by experiment, and this has already been done, it is a simple matter to make the length in pure tension any quantity considered desirable, and this need only be a small fraction of an inch. Further experiment will be

FIG. 26.



Proposed modified form of the British standard cement briquette to give uniform tensional stress at the central cross-section.

necessary to find in the cement briquette the stress distribution at the waist at various ages. It has been established by recent measurements that there is uniformity of lateral contraction under load in each type of briquette lengthened in this way, thereby indicating the probability that uniform tension exists at these central cross-sections.

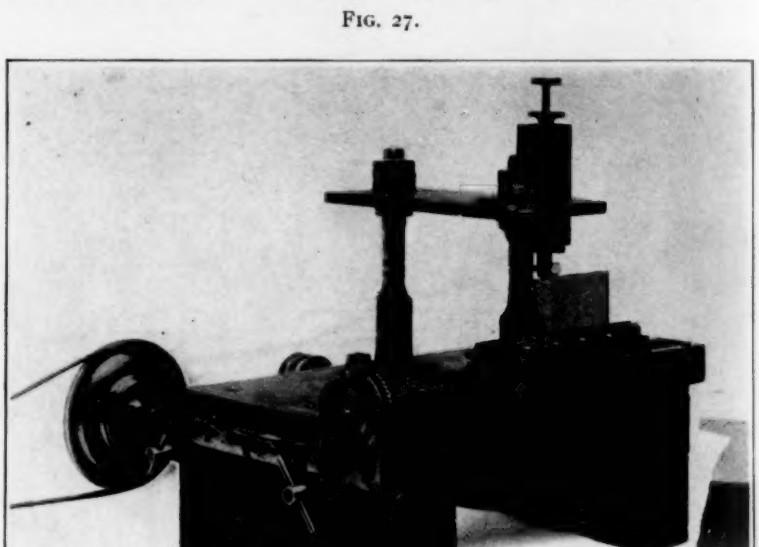
Should there be no further difficulties it would only be necessary to alter the molds now in use to obtain not only uniformity in the comparison of results, but also a real tension test of cement,

which there is some reason to believe has never yet been attained under existing conditions, owing to the variable tension at the waist, and the want of correspondence of this variability in briquettes of different patterns.

THE ACTION OF CUTTING TOOLS.

The problems of contact stress described in the former lecture lead on naturally to the vastly important subject of the action

FIG. 27.



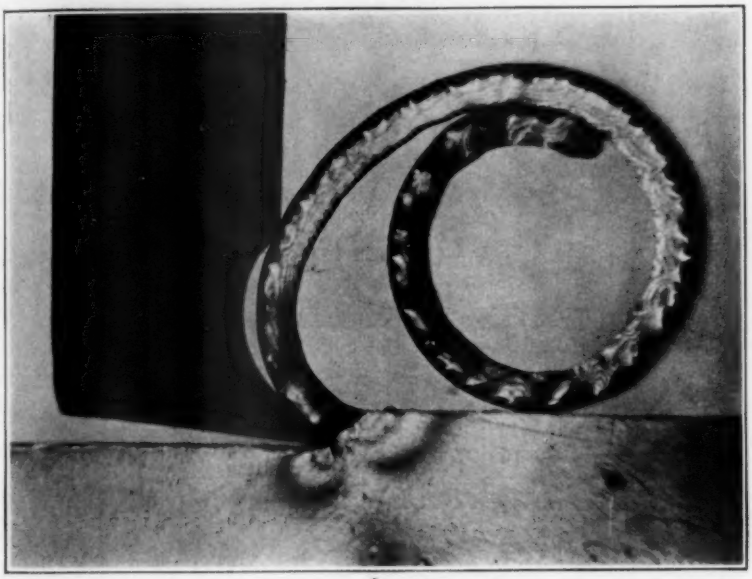
Machine for photo-elastic experiments on planing tools.

of cutting tools, and it is proposed in the remaining time to describe some recent work which was undertaken at the suggestion of Sir John Dewrance, the Chairman of the Cutting Tools Research Committee of The Institution of Mechanical Engineers, in which the action of glass and steel tools when cutting transparent materials has been examined by photo-elastic experiments.

For this purpose it has been necessary to construct special machines which will allow of this form of experiment, and a very simple one is shown in Fig. 27 for studying the action of a planing tool. For this purpose a strip of transparent material

is mounted on a slide rest, the leading screw of which is rotated by gearing operated from a small motor. For convenience the tool is secured in a suitable head having a micrometer feed to give any desired depth of cut, and also arranged to allow the tool to be reversed for cutting on the return stroke. The dispositions of the various parts of the machine are such that all the necessary

FIG. 28.



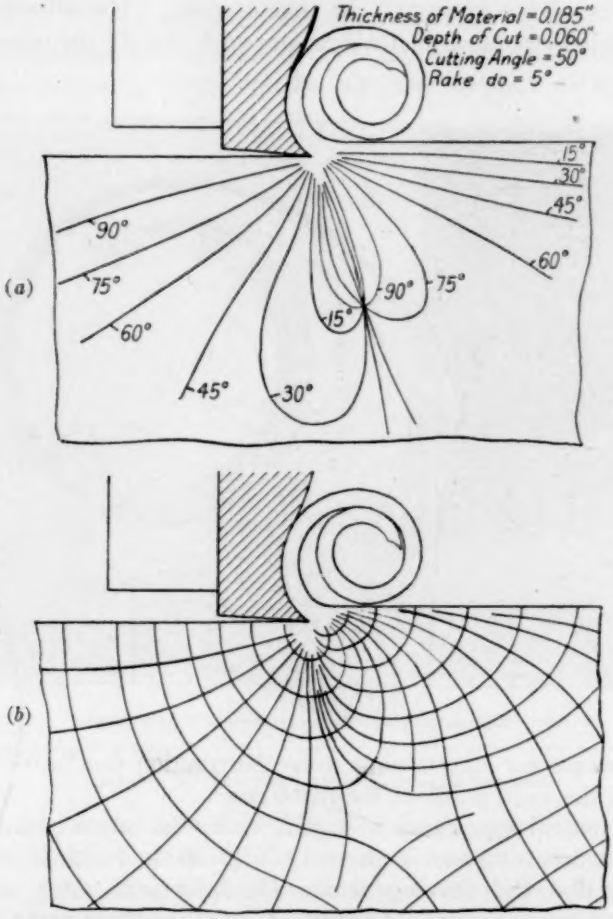
A steel planing tool operating on transparent nitro-cellulose.

measurements for ascertaining stress distribution can be made up to nearly the yield point of the material.

The general appearance of a plate under the action of a fairly well-ground cutting tool is shown in Fig. 28, in which it will be observed that the shaving removed exhibits the most intense permanent stresses which, however, are less than those experienced at or near the cutting edge of the tool, since there the colors disappear entirely and a black patch is visible which remains stationary in time during the whole of the cut. It will also be noticed that the further curling up of the shaving intensifies the stress effects at its tail. The main points of interest are, however, the stresses produced in the work and the tool.

As regards the former it will be noticed that color bands spring from near the point of the tool and in this instance form two distinct lobed systems approximately circular in form and sepa-

FIG. 29.



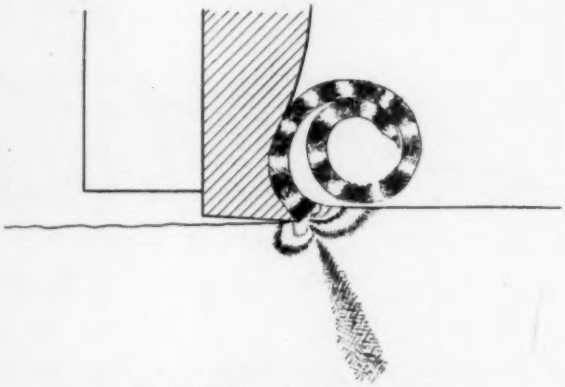
(a) Isoclinic bands in nitro-cellulose under the action of a planing tool.
(b) Lines of principal stress in nitro-cellulose under the action of a planing tool.

rated by a black band or brush. The optical effects in fact correspond somewhat to those shown in Fig. 17, if a diagonal plan of division *AB* is drawn through the centre of the latter and the upper part removed.

All these color phenomena appear stationary in time provided

the tool remains very sharp, but if the edge becomes at all blunt the color bands have an oscillatory motion and wax and wane in a very marked way. In order to find out what distribution of stress these color bands correspond to, a number of measurements have been made along radial lines from the point of the tool, and these show that the stress system in the area of the plant in front of the tool and black brush is roughly that of radial compression varying inversely as the distance from the point of the tool and directly as the cosine of the angular displacement from the centre line of the black brush referred to above. In the

FIG. 30.

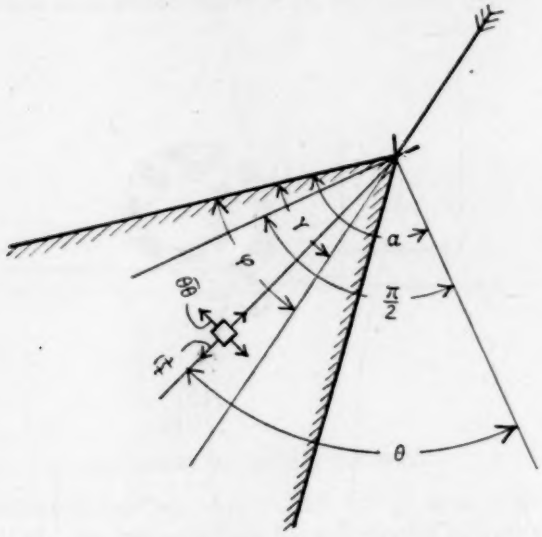


The effect of a badly ground planing tool.

corresponding area to the left of this the measurements indicate a radial tensional distribution of the same nature. It is, however, apparent that this description is only a first approximation to the actual conditions, since, if it were exactly correct, the isoclinic curves would be radial lines and coincide with one system of principal stress lines, the other set being circles with the point of the tool as centre. Actually, however, the isoclinics are curves, which bend round and intersect on the dark brush in a rather complicated fashion, as Fig. 29 shows, and the lines of principal stress are correspondingly complicated in the same area. There are in fact minor principal stresses distributed over the plate area in the neighborhood of the tool point, which must be regarded as additions to an approximately radial system of stresses such as would be caused by the tool exerting a concentrated pressure on the plate at an angle to the radius.

The behavior of a badly ground tool is still more complicated, as it appears to act like a wedge driven into the material so as to break off the shaving by a series of intermittent actions of a cyclical nature. This type of cutting, if it may be dignified by such a name, is shown in Fig. 30, in which it will be seen that the shaving has black patches separated by light colored areas. Observations show that these black patches are due to the upper

FIG. 31.



Theory of stress distribution in a tool making light cuts.

face of the tool bending back the shaving until it is broken away at these places, accompanied by a notable augmentation of the color bands until the shaving is separated from the plate, when the color bands contract and the work advances for a brief interval until it is again arrested by a further resistance due to the necessity of a further separation. The tearing away of the shaving leaves the edge of the plate with an irregular, wavy outline, which only roughly approximates to a truly flat surface.

The Stress Distribution in a Cutting Tool.—Experiments on glass tools appear to show that the stress system in the tool is possibly of a simple type, since, as can be observed, there are

bands of color springing from the point of the tool, which appear to indicate that there is only radial stress in it of the type

$$\widehat{rr} = \frac{2\,C \cdot \cos(\alpha - \varphi)}{r} \tag{12}$$

where α is the angle which the cutting edge makes with the direction of maximum stress, and φ is the angle which this latter edge makes with the direction of the load concentrated at the point of the tool (Fig. 31).

If this be the case, the total component of stress measured in the direction of the zero radius is

$$\int_{\alpha-\gamma}^{\alpha} \widehat{rr} \cdot \cos\theta \cdot r \cdot d\theta = C\left\{\gamma + \cos(2\alpha - \gamma) \cdot \sin\gamma\right\} \tag{13}$$

and in the direction at right angles

$$\int_{\alpha-\gamma}^{\alpha} \widehat{rr} \cdot \sin\theta \cdot r \cdot d\theta = C\left\{\sin(2\alpha - \gamma) \cdot \sin\gamma\right\} \tag{14}$$

and the force P at the apex is therefore

$$P = C\sqrt{\left\{\gamma + \cos(2\alpha - \gamma) \cdot \sin\gamma\right\}^2 + \left\{\sin(2\alpha - \gamma) \cdot \sin\gamma\right\}^2} \tag{15}$$

while its direction is given by

$$\tan(\alpha - \varphi) = \left\{\sin(2\alpha - \gamma) \cdot \sin\gamma\right\} / \left\{\gamma + \cos(2\alpha - \gamma) \cdot \sin\gamma\right\} \tag{16}$$

These results, due to Michell,[21] have been shown to apply very closely to the case of a tool when the action is at or near the cutting edge and it seems probable, except for heavy cuts, that this is the ruling type of stress distribution at and near the cutting edges when well supported from the rear face of the tool.

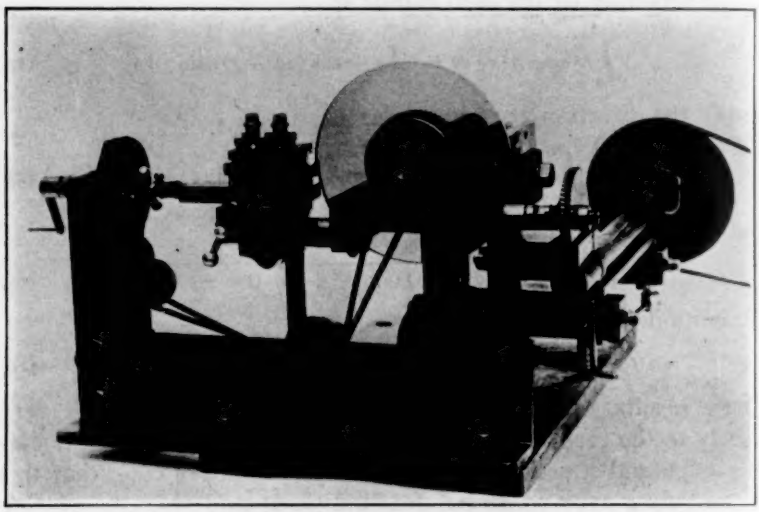
Similar experiments on turning tools have also been carried out in a small lathe specially built to allow a beam of light to be transmitted through the work and the tool, and the general construction of this piece of experimental apparatus is shown in Fig. 32, in which the main spindle of the lathe carrying a transparent disc is revolved by a motor, which latter is belted up to a first motion shaft, driving a second motion shaft by a worm gear. This second shaft is geared to the lathe spindle by a second worm-gear drive as indicated, and the disc turns at a sufficiently low speed to allow all the optical and lateral measurements to be made by modifications of the apparatus already described.

[21] *Proc. London Math. Soc.*, **34** (1902). Appendix (34).

An ordinary form of compound slide rest is used to carry the tool, with the addition of a backstop to prevent radial slip, and there is also an automatic feed for the lower slide. This feed is accomplished by a belt connecting a three-sheaved pulley on the second motion shaft, with a pulley on the screw shaft of the slide rest.

This latter arrangement is found to give a very uniform radial feed when adjustable pulleys are provided for regulating

FIG. 32.



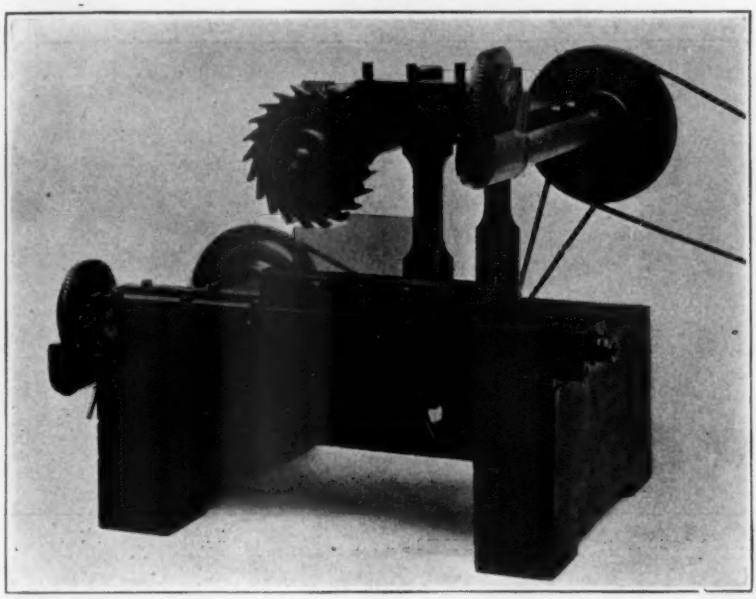
Experimental lathe for photo-elastic experiments with turning tools.

the belt tension, and the general phenomena observed are very similar to those described here in relation to planing tools and have already been very fully described.[22] A more complicated case has been examined recently in which several cutting edges are acting simultaneously as in milling operations. For this purpose another machine was constructed, as shown in Fig. 33, in which, with the exception of the tool-holder, the principal elements of the two former machines are combined to allow the rotary cutter to operate upon a transparent plate secured to a small table which is advanced uniformly by a worm-gear system operated from the main shaft and actuating the screw feed of the slide rest in the foreground. It is of interest to note that in this form of

[22] Appendix (34).

cutting action the shaving grows in thickness as the cut proceeds owing to the fact that the path of the point of the tool is a trochoidal curve, and while the horizontal intercepts between adjacent curves are constant, the radial intercepts increase with the angular motion of the cutter. It is also of interest to note that the final surface produced by a milling cutter operating in a straight line is essentially of a wave form, approximating, it is

FIG. 33.



Milling machine for photo-elastic experiments.

true, to a plane when the rotation of the cutter and the feed are suitably arranged, but never quite reaching the ideal flat surface.

As may be expected, the presence of two or more cutting edges operating at one time to remove shavings of gradually increasing thickness is somewhat complicated, as will be seen in Fig. 34, in which it will be observed that the stress color bands observed previously again reappear, but the stress intensity varies somewhat with the depth of cut. Thus in the foremost operating cutter intensity is very marked as compared with the cutting edge on the extreme left, although the stress systems round each point are similar. At the contour between them a point must be reached

at which the compression stress caused by an advancing tooth is reduced to zero by the tensional stress caused by the drag of the tooth in advance, and the small black patch on the contour and somewhat to the left of the centre indicates the position of this zero stress. Measurements of the stress distribution in the plate confirm this.

The appearance of the shavings removed are also of interest, since the alternations of light and dark patches show that the

FIG. 34.

A milling cutter in action.

material is being wedged off with little or no true cutting action. The cut surface obtained is not, however, found to be so rough as in surfaces operated upon by one cutter and giving a similar action, since the final surface produced is an aggregation of small faces produced at the commencement of the cut when the shaving is thin and the wedging-off action is not so pronounced.

Although much other work has been carried out on these lines in an attempt to understand the action of cutting tools, this brief description is probably sufficient to show that photo-elastic research is a means which is fruitful of results, even in so old and well-cultivated a field of experimental investigation as that of the action of cutting tools.

APPENDIX.

PAPERS ON PHOTO-ELASTICITY.

BY PROF. E. G. COKER AND COLLABORATORS.

(1) "Note on the Application of Polarized Light to Determine the Condition of a Body under Stress," Profs. S. P. Thompson and E. G. Coker, *B. A. Report*, 1909.

(2) "The Optical Determination of Stress," *Phil. Mag.*, Oct., 1910.

(3) "Photo-elasticity," *Engineering*, Jan. 6, 1911.

(4) "The Determination, by Photo-elastic Methods, of the Distribution of Stress in Plates of Variable Section, with Some Applications to Ships' Plating," *Trans. Inst. Naval Architects*, 1911.

(5) "The Use of Polarized Light as an Aid to Determining the Effect of Stress in Engineering Materials," *Proc. Sheffield Soc. Eng. and Metal.*, 1911.

(6) "An Optical Determination of the Variation of Shear Stress in a Thin Rectangular Plate Subjected to Shear," *Proc. R. S.*, 1912.

(7) "Color Photography of Internal Stress in Bodies of Engineering Forms," West of Scotland Iron and Steel Institute, 1912.

(8) "The Determination of the Stresses in Springs and other Bodies by Optical and Electrical Methods," *B. A. Report*, Section G, 1912, and *Engineering*, Sept., 1912.

(9) "The Design and Construction of Large Polariscopes," Profs. E. G. Coker and S. P. Thompson, *Proc. Optical Convention*, **2**, 1912.

(10) "The Applications of Polarized Light to Mechanical Engineering Problems of Stress Distribution," *Proc. Inst. Mech. Engineers*, 1913.

(11) "Column Testing Machine," *Proc. Phys. Soc., Lond.*, 1913.

(12) "The Effects of Holes and Semi-circular Notches on the Distribution of Stress in Tension Members," *Proc. Phys. Soc., Lond.*, **25**, Part II, 1913.

(13) "The Distribution of Stress at the Minimum Section of a Cement Briquette," International Association for Testing Materials, New York Congress, 1913.

(14) "The Measurement of Stresses in Materials and Structures," Cantor Lectures, Royal Society of Arts, 1913.

(15) "The Distribution of Stress Due to a Rivet in a Plate," Prof. E. G. Coker and Mr. W. A. Scoble, *Trans. Inst. Naval Architects*, 1913.

(16) "The Stress Distribution in Short Compression Members," Profs. E. G. Coker and Filon, *B. A. Report*, 1914.

(17) Presidential Address to Section G (Engineering) of the British Association at Sydney, *B. A. Report*, 1914.

(18) "Experimental Determination of the Distribution of Stress and Strain in Solids," Profs. Filon and E. G. Coker. Report of the Committee on Stress Distributions in Engineering Materials, *B. A. Report*, 1914.

(19) "Gli sforzi interni nei materiali da costruzione determinati mediante la luce polarizzata," Prof. E. G. Coker, *Annali Societa d'Ingegneria e Architetti*, 1916.

(20) "Il metodo sperimentale del Prof. E. G. Coker per determiniane gli sforzi interni nei materiali da costruzione mediante la luce polarizzata, Prof. L. Luiggi, *Annali Societa d'Ingegneria e Architetti*, 1916.

(21) "Polarized Light and its Applications to Engineering," Friday Evening Discourse Royal Institution, 1916.

(22) "The Stress in the Fillets of a Crank Shaft," Report on the Materials of Construction Used in Aircraft, Aeronautical Research Committee, 1920. Edited by Prof. C. F. Jenkin.

(23) "Photo-elasticity for Engineers," *Proc. Inst. Autom. Engs.*, 1917.

(24) "Photo-elastic Measurements of the Stress Distribution in Tension Members Used in the Testing of Materials," *Min. Proc. Inst. Civil Eng.*, **208**, 1918–19.

(25) "Photo-elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members," Prof. E. G. Coker, Messrs. K. C. Chakko and Y. Satake, *Proc. Inst. Engineers and Shipbuilders in Scotland*, 1919.

(26) "The Stress-strain Properties of Nitro-cellulose and the Law of its Optical Behavior," Prof. E. G. Coker and Mr. K. C. Chakko, *Phil. Trans. R. S.*, 1920.

(27) "The Effects of Holes, Cracks and Other Discontinuities in Ships' Plating," Prof. E. G. Coker and A. L. Kimball, *Trans. Inst. Naval Architects*, 1920.

(28) "Tension Tests of Materials," *Engineering*, Jan., 1921.

(29) "Stress Concentration Due to Notches and Like Discontinuities," Prof. E. G. Coker and Dr. Paul Heymans, *B. A. Report*, 1921, also reprinted in *Engineering*.

(30) "Contact Pressures and Stresses," Prof. E. G. Coker, K. C. Chakko and M. S. Ahmed, *Proc. Inst. Mech. Engineers*, 1921.

(31) "The Effects of Scratches in Materials," Engineering Conference, The Inst. Civil Engineers, 1921.

(32) "Recent Researches in Photo-elasticity," *Proc. Sheffield Soc. Eng. and Metal.*, 1921.

(33) "Photo-elasticity for Engineers," six lectures delivered at the Research Laboratory of the General Electric Company, Schenectady, New York, and afterwards published in General Electric Company's Magazine, 1920–21.

(34) "An Account of Some Experiments on the Action of Cutting Tools," Prof. E. G. Coker and K. C. Chakko, *Proc. Inst. Mech. Eng.*, 1922.

(35) "Curved Beams, Rings and Chain Links" (Honorary Members' Lecture), *Jour. Jr. Inst. Eng.*, 1922.

(36) "Des Recherches Récentes sur la Photo-Elasticimétrie ayant rapport à son application dans les Problèmes Posées en Construction," La Société des Ingénieurs Civils de France, 1922; see also *Engineering*, June 16, 1922.

THE VALUES OF THE ELECTRICAL MOMENTS OF THE ATOMS AND THEIR CONNECTION WITH OTHER QUANTITIES.*

BY

R. D. KLEEMAN, B.A., D.Sc.

Research Physicist and Physical Chemist, Union College and the General Electric Company, Schenectady, New York.

SINCE an atom consists of a number of electrons distributed around a positive nucleus, its electrical effect at a distant point would be equivalent to an electrical doublet. The force between two atoms, which may be either an attraction or a repulsion, depending on the way the representative doublets face each other, would, accordingly, be proportionate to the product of the electrical moments of the atoms, and inversely proportional to the fourth power of their distance of separation. When the atoms or molecules are free to move about as in a gas or liquid their electrical doublets would tend to arrange themselves with respect to each other, as the writer has pointed out,[1] so that the potential energy would be a minimum. The outstanding force would therefore be attraction, and if repulsion occurs, it would be as small as possible. Thus there would be an association between the directions of the axes of the atomic doublets at every instant, though all directions of the axis of each doublet are equally probable, since the substance as a whole does not possess any polarity. But the attraction between two atoms or molecules in a substance at constant temperature would not follow the inverse fourth power law, since the orientation of the molecules with respect to each other at any instant would depend on the nature and number of collisions they undergo per second, which would depend on the density and temperature of the substance. The attraction between two atoms or molecules of electrical moment M corresponding to the average distance of separation z of the molecules of the substance would accordingly be given by

$$\psi(z, T) \cdot \frac{M^2}{z^4},$$

* Communicated by the Author.

[1] *Phys. Rev.*, **18**, 4, p. 303.

where the function $\psi(z, T)$ expresses the effect of molecular collision on the law of molecular attraction. The effect of molecular collision in interfering with the tendency of the molecules to set themselves so that attraction is the outstanding force, and that it be as great as possible, will evidently increase with increase in temperature. We would therefore expect that the function $\psi(z, T)$ should decrease in value with increase in temperature for a constant value of z.

The writer has deduced [2] from various experimental data that the attraction between two molecules is given by

$$\phi\left(\frac{z}{z_c}, \frac{T}{T_c}\right)\frac{(\Sigma c_a)^2}{z^5},$$

where Σc_a denotes the sum of a number of atomic constants each of which is very approximately proportional to the square root of the atomic weight of the atom to which it refers, z_c is the distance of separation of the molecules at the critical point, and T_c the critical temperature. The function ϕ does not appear to vary much with either z or T. It follows from this result that the electrical moment of an atom is proportional to the square root of its atomic weight, and that the moment of a molecule is equal to the sum of the moments of its atoms. This would explain, as the writer has shown,[3] the stopping power law of the α particle. It also follows from the above law that the effect of molecular collision in modifying the inverse fourth power law is represented by the factor $\phi\left(\frac{z}{z_c}, \frac{T}{T_c}\right)\frac{1}{z}$ in the law of molecular attraction.

The square root of the atomic weight of an atom is very approximately proportional to the two-thirds power of its atomic number, according to Glasson.[4] And since the atomic number N is equal to the number of elementary electrical charges associated with the atom, the distance of separation x of the two charges in the representative electrical doublet of the atom, is given by

$$xNe = k_1 N^{\frac{2}{3}}$$

or

$$x = k_2 N^{-\frac{1}{3}} \qquad (1)$$

where k_2 is a constant. Thus x decreases with increase of the atomic weight of an atom. This is probably due to the fact that

[2] *Phil. Mag.*, May, 1910, p. 783; Jan., 1911, p. 83. *Proc. Camb. Phil. Soc.*, 16, pt. 7, p. 583.

[3] *Loc. cit.*

[4] *Phil. Mag.*, 43, p. 477.

the larger the atom the more symmetrical its electrons are likely to be distributed around the positive nucleus.

The forces between atoms and molecules have been explained by Debye [5] along electrical lines by assuming that during their motion of translation and collision with each other they undergo contractions and expansions successively in such a manner that attraction would be the outstanding force. But it is evident from the theory proposed by the writer that such an assumption need not be introduced, is, in fact, quite unnecessary. Nevertheless, such expansions and contractions may, and probably do, take place, but they would not form the dominating factor in determining the nature of the forces the molecules exert upon each other.

It can easily be shown from the facts that the factor $\psi(z, T)$ in the law of attraction is not a constant but a function of z and T. Thus if we assume that it is a constant, it can easily be shown [6] that the internal heat of evaporation L of a liquid is given by

$$L = a(\rho_1 - \rho_2) \qquad (2)$$

where ρ_1 denotes the density of the liquid and ρ_2 that of the vapor, and a a constant which depends on the nature of the liquid. Table I, taken from the paper quoted, gives the values of $L/\rho_1 - \rho_2$

TABLE I.

Ethyl Oxide.				Carbon Tetrachloride.				Methyl Formate.			
T	$\frac{L}{\rho_1-\rho_2}$	T	$\frac{L}{\rho_1-\rho_2}$	T	$\frac{L}{\rho_1-\rho_2}$	T	$\frac{L}{\rho_1-\rho_2}$	T	$\frac{L}{\rho_1-\rho_2}$	T	$\frac{L}{\rho_1-\rho_2}$
273	117.1	393	100.2	273	29.6	473	25.3	273	112.9	443	89.5
313	109.9	433	93.4	393	27.4	513	24.4	323	107.6	483	73.4
353	104.7	460	88.7	433	26.4	553	22.1	403	95.6	496	68.1

at different temperatures for a number of substances. It will be seen that they decrease with increase of temperature.

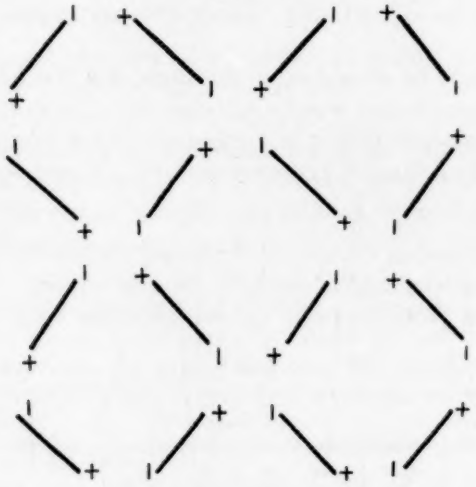
The nature of the function $\psi(z, T)$ cannot be determined from the variations of a since they are due to *simultaneous* variations of z and T. The moment of an atom or molecule cannot, therefore, be determined from data on the internal heat of evaporation for temperatures above the absolute zero. But it is possible to

[5] *Phys. Zeit.*, **21**, p. 178 (1920).

[6] *Phil. Mag.*, Oct., 1910, p. 677.

carry this out at a temperature at, or near, the absolute zero, as will now be shown. At such a temperature the number of collisions a molecule undergoes per second with other molecules is very small, and the tendency of the molecules to set themselves so that the attraction between them is as large as possible will, therefore, be little affected. The resultant distribution of the axes of the molecular electrical doublets in space would obviously be such that the force acting on a molecule is on the average the same in any two opposite directions. It will also not be difficult to see

FIG. 1.



that the nature of the distribution would depend somewhat on the density of the substance. The average distribution may be approximately obtained without incurring mathematical difficulties.

Before proceeding to obtain this distribution, it should be pointed out that the molecules of a substance in the condensed state at the absolute zero of temperature do not strictly behave as electrical doublets, since they are in equilibrium under the action only of their forces of attraction and repulsion, on account of the absence of motion of translation. The existence of these forces would be shown by the nature of the resistance that would be encountered on expanding or compressing the substance. Since we infer from the behavior of substances at ordinary tempera-

tures that the coefficient of compression would be extremely small at the absolute zero, which naturally holds also for the coefficient of expansion, a small expansion of the substance would cause great forces of attraction between the molecules to come into play, or the molecules would behave like electrical doublets under the new conditions. Thus only over a small range of densities the molecules are not likely to behave as electrical doublets.

The average positions of the molecules in space would correspond to the points of intersection of three sets of parallel and equidistant planes at right angles to each other, since this distribution fulfils the condition that the potential energy corresponding to a given density of the substance is a minimum. Let us suppose that the axes of the doublets lie on diagonals of the cubes formed by the foregoing planes of reference in such a way that a projection of the doublets, whose centres lie on a plane, on to this plane, gives an arrangement as shown in Fig. 1, in which the projected axes are situated at right angles with opposite charges facing each other. The force acting on a doublet, which is an attraction, will evidently be the same in three directions at right angles to each other, and is as large as is possible under these conditions.

Now the attraction between two doublets lying on a plane, and making angles θ_1 and θ_2 with the line joining their centres is

$$-3\frac{M^2}{r^4}(2\cos\theta_1\cos\theta_2-\sin\theta_1\sin\theta_2).$$

The attraction between two doublets whose centres are situated on a line formed by the intersection of the foregoing planes of reference is therefore given by

$$4.5\frac{M^2}{r^4},$$

since the doublets lie on a plane and are inclined at an angle of 45° to the line joining their centres. The attraction between two doublets not lying in the same row will evidently be less than that given by the above expression. For our purpose it is necessary to obtain the average law applying to any pair of doublets. An approximation to this law is obtained from the following considerations.

Two doublets lying on the same straight line, with opposite charges facing each other, exert upon each other the attraction

$$6\frac{M^2}{r^4}.$$

If the axes of the doublets are parallel and opposite charges face each other, the attraction is

$$3\frac{M^2}{r^4}.$$

Thus, if a doublet is placed at the origin of a system of rectangular axes, and a doublet on each axis some distance from the origin, the attraction along one axis will be given by the first of the foregoing expressions, and that along each of the remaining two axes by the second expression, if the doublets are parallel to one of the axes and so arranged that the force is attraction. But we have seen that the average distribution of the axes of the doublets in space is such as to give the same attraction along three rectangular axes. Now we may suppose the above system of coördinates to rotate around its origin, and therefore the general representative law of attraction that may be taken to hold for any pair of doublets is *approximately* given by the mean of the foregoing expressions, which is

$$\frac{6+3\times 2}{3}\frac{M^2}{r^4}=4\frac{M^2}{r^4}.$$

The attraction given by this expression is a little less than that given by the preceding investigation, as should be the case if it is to represent the average law. Since the exact determination of the average law leads to mathematical difficulties, and it is not likely to differ much from the foregoing law, this will be used in the investigations in this paper, whose main object is to determine the absolute value of the moment of an atom.

The process may be considerably shortened by using a result obtained previously by the writer. It was shown[7] that if the attraction between two molecules or atoms is given by

$$\frac{K_1}{z^5},$$

[7] *Proc. Camb. Phil. Soc.*, 16, pt. 7, p. 593 (1912).

where z denotes their distance of separation and K_1 a constant, the internal heat of evaporation in ergs per gram, in the particular case that the vapor obeys the gas laws, is given by

$$L = 1.58 \frac{\rho_1^{4/3}}{m_a^{7/3}} K_1,$$

where ρ_1 denotes the density of the substance and m_a the absolute mass of an atom or molecule. This expression for L involves the factor obtained by the integration of

$$\int_z^\infty \frac{1}{z^5} \cdot dz,$$

which gives

$$\frac{1}{4z^4} = \frac{1}{4}\left(\frac{\rho_1}{m_a}\right)^{\frac{4}{3}},$$

where

$$\left(\frac{m_a}{\rho_1}\right)^{\frac{1}{3}} = z$$

denotes the distance of separation of the molecules. The latent heat expression corresponding to the law of attraction

$$\frac{K_1}{z^4}$$

is therefore obtained from the foregoing expression on multiplying it by

$$\frac{1}{3}\left(\frac{\rho_1}{m_a}\right)^1 \Big/ \frac{1}{4}\left(\frac{\rho_1}{m_a}\right)^{\frac{4}{3}},$$

which gives

$$L = 2.106 \frac{\rho_1}{m_a^{\frac{1}{3}}} K_1.$$

If this equation is applied to the absolute zero of temperature we have

$$L_0 = 8.42 \frac{\rho_0}{m_a^{\frac{1}{3}}} M^2 \qquad (3)$$

since we have just shown that

$$K_1 = 4 M^2$$

in that case, where L_0 denotes the latent heat and ρ_0 the density at the absolute zero.

TABLE II.

		r_0	T	ρ_1	L in cal.	m	L_0 in cal.	$M\,10^{12}$	$\Sigma N^{2/3}$	$\frac{M\,10^{12}}{\Sigma N^{2/3}}$
Iodobenzene	C_6H_5I	89.9	303	1.8149	53.75	203.9	83.9	3.51	38.9	9.03
Chlorobenzene	C_6H_5Cl	79.0	273	1.1278	82.90	112.5	132.2	3.08	31.4	9.77
Fluorbenzene	C_6H_5F	70.6	273	1.0465	81.74	96.09	138.1	2.74	29.1	9.42
Bromobenzene	C_6H_5Br	82.2	303	1.4815	64.84	157.	107.6	3.33	35.5	9.40
Stannic chloride	$SnCl_4$	87.	273	2.2789	33.3	260.8	57.62	3.25	40.0	8.12
Carbon tetrachloride	CCl_4	72.7	273	1.6327	48.35	153.8	81.12	2.70	29.7	9.10
Benzene	C_6H_6	66.4	273	.9001	100.16	78.05	170.6	2.66	25.8	10.31
Octane	C_8H_{18}	123.5	273	.7185	84.71	114.14	119.9	3.83	44.4	8.62
Pentane	C_5H_{12}	80.7	273	.6454	85.85	72.10	164.4	2.77	28.5	9.71
Ethyl ether	$C_4H_{10}O$	72.6	273	.7362	86.16	74.	165.1	2.67	27.2	9.80
Acetone	C_3H_6O	53.2	273	.8186	131.82	58.	223.2	2.35	20.9	11.24
Carbon disulphide	CS_2	45.	273	1.2921	82.76	76.	141.3	1.97	16.0	12.29
Sulphur dioxide	SO_2	31.	263	1.460	86.56	64.	173.0	1.66	14.36	11.55
Carbon dioxide	CO_2	25.5	243	1.045	65.34	44.	177.8	1.27	11.3	11.20

The value of L_0 may be obtained by exterpolation from an empirical latent heat equation. The one best suited for this purpose is

$$L = (\rho_1^2 - \rho_2^2)\, k_3$$

given by Batschinski [8] and the writer,[9] where ρ_1 denotes the density of the liquid and ρ_2 that of the vapor. At low temperatures ρ_2 may be neglected in comparison with ρ_1. The constant k_3 may be determined by applying the equation to the substance at a temperature for which ρ_1 and L are known, and L_0 would accordingly be given by

$$L_0 = \left(\frac{\rho_0}{\rho_1}\right)^2 L \qquad (4)$$

Table II contains the values of L_0 for a number of substances, and the values of L, ρ_1 corresponding to the given values of the absolute temperature T and the values of $\frac{m}{\rho_0} = v_0$, used for their calculation, where m denotes the molecular weight relative to hydrogen, and v_0 the molecular volume per gram molecule at the absolute zero of temperature. The values of L and ρ_1 were obtained from papers by Mills,[10] and the exterpolated values of v_0 from a paper by Traube.[11] The values of L_0 thus obtained were used to calculate the values of M by means of equation (3), the results being given in the table. On examining them it will appear that the electrical moment of a molecule is equal to the sum of the electrical moments of its atoms, and that the moment of an atom is proportional to the two-thirds power of its atomic number N. Thus if the ratio $M/\Sigma N^{\frac{2}{3}}$ for the various molecules is obtained, it is found to be approximately a constant, as is shown by the last column of Table II. The mean value of this ratio is 10^{-19}. The electrical moment M_a of an atom is accordingly given by

$$M_a = 10^{-19} N^{\frac{2}{3}} \qquad (5)$$

and that of a molecule by

$$M = 10^{-19} \Sigma N^{\frac{2}{3}} \qquad (6)$$

In the foregoing investigation we have used only two assumptions which may really be classed as such, namely, that atoms and

[8] *Ann. der Physik*, **14**, p. 305 (1904).
[9] *Phil. Mag.*, Oct., 1910, pp. 678–682.
[10] *Jour. Phys. Chem.*, **8**, p. 405 (1904), etc.
[11] *Phys. Zeit.*, Oct., 1909, p. 667.

molecules possess definite electrical moments in their interaction with each other, and that these moments at the absolute zero of temperature are approximately independent of the density of the substance between that corresponding to the condensed state and the vaporous state inclusive. They led to the remarkable results expressed by equations (5) and (6). These constitute, I think, strong evidence that the assumptions made are true. Every theory of the distribution of the electrons and the positive charges in an atom must therefore take into account that, at distances from the centre of the atom greater than its diameter, it behaves as if it consists of an electrical doublet.

Since the moment of an atomic doublet is $10^{-19} N^{\frac{2}{3}}$ according to equation (5) and it was previously expressed in this paper in the form xNe, it follows that $k_2 = \frac{10^{-19}}{e}$ in equation (1). Therefore, on taking e equal to 4.77×10^{-10} e.s.u. (Millikan's value), we obtain

$$x = 2.09 \times 10^{-10} N^{-\frac{1}{3}} \text{ cm.} \qquad (7)$$

from this equation. The distance of separation x of the electrical charges in the representative doublet of an atom is thus much smaller than its diameter. It will be of interest to examine this result more closely. In the case of the hydrogen atom, which is supposed to consist of an electron rotating in a circle the centre of which is occupied by the positive nucleus, we have $N = 1$ and hence $x = 2.09 \times 10^{-10}$ cm. The value of x is obviously much less than the diameter of the atom, which is of the order of 10^{-8} cm. According to Bohr's investigations in connection with the origin of spectra the distance of the rotating electron from the nucleus is $.53 \times 10^{-8}$ cm. Thus, in order that the atom may behave as an electrical doublet, it is necessary that the nucleus does not occupy the centre of the circular path of the electron but a point a distance $x = 2.09 \times 10^{-10}$ cm. from the centre at right angles to the plane of motion. Strictly, the system will not be in equilibrium under these conditions according to the known laws. But this is not a very serious objection since there is a great deal of evidence along other lines that the motion of an electron is an atom does not obey the Newtonian dynamics. If the electron describes an ellipse with the nucleus at one of the foci, the atom might behave on the whole as a doublet. It is, however, more likely that the doublet effect is brought about in the way first suggested. It is also very

likely that the doublet effect of the more complicated atoms is mainly caused by the positive nuclei not occupying the foci of the paths of the moving electrons.

The inductivity of a substance, it is scarcely necessary to point out, is easily explained if its atoms and molecules behave as electrical doublets. An electric field applied to the substance would tend to set these doublets parallel to itself, while the collisions the molecules undergo would tend to interfere with this tendency, since a collision between two doublets would suddenly change the directions of their axes. The inductive effect of a substance subject to an electric field may therefore be represented by assuming that the doublets are stationary in space and set with their axes inclined at an angle to the lines of electric force depending on the intensity of the field. This angle can be calculated, knowing the magnitude of the moments of the atoms.

If it is assumed that the inductivity is caused by the atoms behaving as perfect conductors of electricity of spherical form, and v denotes their total volume per c.c., the dielectric constant K, according to the well-known Mossotti Clausius equation, is given by

$$K = \frac{1 + 2v}{1 - v}$$

or

$$v = \frac{K - 1}{2 + K} \tag{8}$$

Now when an atom of radius r is placed in an electric field of intensity H in e.s.u., a doublet of moment Hr^3 is induced whose axis is parallel to the electric lines of force. This doublet may be taken to arise from the projection of the molecular doublet on to the direction of the lines of force, and hence we may write

$$Hr^3 = M \cos \theta$$

We also have

$$. \quad = n\pi r^3 \frac{4}{3},$$

where n denotes the number of molecules per c.c., and therefore

$$v = \frac{4}{3} n\pi \frac{M \cos \theta}{H}.$$

Since all the quantities this equation contains are constants except $\cos\theta$ and H, it follows that these two quantities are proportional to each other, and we may therefore write

$$v = \frac{4}{3} n \pi M \cos\theta' \qquad (9)$$

where the angle θ' corresponds to an electric field of unit intensity. From this equation and equation (8) we have

$$\cos\theta' = \frac{K-1}{2+K} \frac{3}{4\pi n M} \qquad (10)$$

where the value of n is given by

$$n = \frac{\rho_1}{m\ 1.66 \times 10^{-24}}$$

Table III gives values of $\cos\theta'$ and of $M \cos\theta'$ for a number of substances in the gaseous state calculated by the foregoing equa-

TABLE III.

Gas.		$\frac{K-1}{K+2}$	$t°$ C.	$M\cos\theta' \times 10^{25}$	$\cos\theta' \times 10^{8}$
Hydrogen	H_2	.000088	0	2.6	1.30
Helium	He	.0000247	0	.728	.459
Nitrogen	N_2	.000194	0	5.73	.782
Carbon dioxide	CO_2	.000328	0	9.67	.762
Methane	CH_4	.000318	0	9.38	1.27
Hydrochloric acid	HCl	.00086	100	34.3	4.52
Carbon disulphide	CS_2	.000796	100	32.1	1.63
Carbon tetrachloride	CCl_4	.001013	110	40.8	1.51
Ethyl bromide	C_2H_5Br	.00515	100	207.5	9.31
Benzene	C_6H_6	.00090	100	36.1	1.36
Methyl formate	$C_2H_4O_2$	.0023	100	92.7	5.93
Methyl acetate	$C_3H_6O_2$	.0024	100	96.7	5.48
Ethyl propionate	$C_5H_{10}O_2$	.0047	100	189.0	6.00

tion. The values of K were obtained from a table given in the "Handbuch der Electrizität und des Magnetismus" by Dr. L. Grätz, and correspond to standard pressure at the temperatures given. The values of M were taken from Table II. It will be seen that in all cases $\cos\theta'$ is a very small fraction, and θ' therefore nearly a right angle. Thus the directive action of an electric field of one electrostatic unit is very small. Evidently an enormous field, of the order 10^6 e.s.u., or 10^8 volts, would be necessary, on account of the disturbing action of molecular collision, to keep the molecular doublets approximately parallel to the lines of electric force. The values of $\cos\theta'$ for different substances are probably strictly comparable only at corresponding states, which

does not apply to the values given in the table. It is evident, however, that they probably would, under ideally comparable conditions, increase with increase in the moment of the molecule, as we might expect. The angle θ' must be besides a function of the nature and frequency of molecular collision, and is thus on the whole a complicated quantity.

We would expect therefore that the more violent the molecular collision the more it would interfere with the doublets tending to set themselves parallel to an electric field. It would follow therefore that the inductivity of a gas kept at constant volume should decrease with increase in temperature, provided no dissociation takes place. This agrees with the facts.

The frequency of molecular collision, which increases with increase of density at constant temperature, should also tend to decrease the value of $\cos\theta'$. On the other hand, the tendency of an atomic doublet to set itself parallel to the electric field will react on the other doublets of the substance, tending to set them in the same direction, which would increase the value of $\cos\theta'$. The effect of one doublet on the other at any instant would of course depend on their distance of separation. The latter effect would increase with increase of density of the substance, and is thus in the opposite direction to the former effect. The relative importance of these two effects will appear on comparing the values of $M\cos\theta'$ for a number of liquids given in Table IV with

TABLE IV.

Liquid.		K.	$t°$ C.	ρ_1	$M\cos\theta'\times10^{18}$
Benzene	C_6H_6	7.316	18	.8808	640.9
Carbon disulphide	CS_2	2.626	20	1.2625	126.
Ethyl oxide	$C_4H_{10}O$	4.68	0	.7362	481.0
.....	.....	4.30	20	.7135	445.2
.....	.....	3.65	60	.6658	383.2
.....	.....	3.12	100	.6105	334.3
.....	.....	2.66	140	.5385	296.8
.....	.....	2.12	180	.4268	252.6
Hexane	C_6H_{12}	1.880	17	.6605	149.3
Octane	C_8H_{18}	1.949	17	.7033	200.3
Acetone	C_3H_6O	26.6	0	.8126	2360.
Carbon dioxide	CO_2	1.60	−5	.930	36.94
Chloroform	$CHCl_3$	5.2	18	1.4885	438.4

those given in Table III for a number of gases. It will be seen that the values for the liquid state are greater than those for the gaseous, and the latter effect is therefore more pronounced for this

state than the former. When a substance is approximately in the perfectly gaseous state these effects are nearly equal since the inductivity under these conditions is found to be approximately proportional to the density of the gas.

An increase in temperature increases the violence of molecular collision and hence the angular velocity of molecular rotation, which would necessarily be attended by a change in the geometrical configuration of the atoms of each molecule. We would therefore expect that the specific heat of a gas should be a function of the electrical moments of the atoms of a molecule. This is found to be the case. Table V gives the specific heat c_v per gram mole-

TABLE V.

Gas.		c_v	c_i	$\frac{\log_{10} c_i}{\Sigma a_\omega^{1/2}}$	$\frac{\log_{10} c_i}{\Sigma N^{2/3}}$
Carbon disulphide	CS_2	8.01	5.07	475	441
Chloroform	$CHCl_3$	14.05	11.11	468	433
Ethyl bromide	C_2H_5Br	12.72	9.78	452	442
Acetone	C_3H_6O	15.30	12.36	536	548
Benzene	C_6H_6	15.48	12.54	410	425
Ethyl acetate	$C_4H_8O_2$	21.00	18.06	424	430
Ether	$C_4H_{10}O$	25.50	22.56	486	497

cule of a number of substances in the gaseous state at constant volume, and the values of $c_v - \frac{3}{2} R = c_i$ where $\frac{3}{2} R$ is the part of the specific heat due to the change in kinetic energy of motion of translation of the molecules. The internal specific heat c_i represents the change in the internal molecular energy per degree change in temperature. It is found that

$$\log_{10} c_i = h_1 \Sigma N^{2/3} = h_2 \Sigma a_\omega^{1/2} \qquad (11)$$

where a_ω denotes the atomic weight of an atom, and h_1 and h_2 are constants, as is shown by the values obtained from this equation and given in the table.

The values of c_v used refer to the temperature 0° C. and were taken from "Winckelmann's Handbuch der Physik," 2nd ed. It is very probable, however, that these quantities are comparable only at corresponding temperatures, in parallel with so many other properties of substances. We would then have

$$\log_{10} c_i = \phi_1 \left(\frac{T}{T_c} \right) \cdot \Sigma N^{2/3} \qquad (12)$$

where T_c denotes the absolute critical temperature, and $\phi_1\left(\frac{T}{T_c}\right)$ a function of T/T_c.

The method of obtaining the absolute value of the electrical moment of an atom developed in this paper could not very well be simpler or more straightforward. Attempts have previously been made by Jona, Frivolds, and Debye [12] to obtain a value of this quantity from data on electric inductivity and cohesion. In order to obtain formulas that can be applied to the facts it was necessary to introduce assumptions which introduced other quantities besides the above. These formulas would therefore naturally not be so trustworthy as the one developed in this paper. The values obtained for the electrical moment of a few molecules are, however, it is interesting to note, of the same order of magnitude as those given by equation (3).

Comparison of Resistance Changes in Longitudinal and Transverse Magnetic Fields. W. H. SANDERS and A. P. CARMAN. (*Phys. Rev.*, Feb., 1923.)—Wire of copper, silver, manganin and also Advance wire were placed in magnetic fields of strengths from 4 to 16 kilogausses, so that the magnetic lines of force were in one position perpendicular to the wires and in the other parallel to them. In both positions the copper and the silver wires showed an increase in the electrical resistance, while in both positions the two alloy wires showed a decrease. For all wires in both positions the change in the resistance increased with increasing field strength. The change in resistance was greater when the wire was transverse to the field than when it was parallel, though in the case of the Advance wire the difference was but slight. This wire showed the least change of resistance and copper the greatest. All changes measured were small, the largest, the change in copper wire, transverse to the field of 16 kilogausses, being 645 ten-millionths of the resistance in the absence of a field. G. F. S.

Chlorine Isotopes in Apatite. MARGOT DORENFELDT, of the University of Christiania (*Jour. Am. Chem. Soc.*, 1923, **45**, 1577–1579), has determined the specific gravity and sodium chloride content of saturated aqueous solutions of ordinary sodium chloride and of sodium chloride whose chlorine content was derived from the mineral apatite mined in Bamle. Her results show that the isotopes of chlorine occur in the apatite in the same proportion as an ordinary sodium chloride. J. S H.

[12] *Phys. Zeit.*, **20**, p. 14; **22**, p. 603; **21**, p. 178.

Action of Potassium Carbonate on Lead Glass. H. DROOP RICHMOND (*Analyst*, 1923, **48**, 260–262) has shown by experiment that potassium carbonate is sufficiently hygroscopic to attack the glass of the bottle in which it is stored, especially if it become moist. A thin film of a very concentrated solution of potassium carbonate forms on the surface of the crystals. If the glass contain arsenic and lead, the film in contact with the glass dissolves these elements as potassium arsenite and plumbate. When the contents of the bottle are disturbed, the contaminated crystals are mixed with the bulk of the carbonate. A bottle had been used continuously for at least nine years as a container for potassium carbonate. The loose salt, which could be removed from the bottle by ordinary shaking, contained seven parts of arsenic and between 200 and 300 parts of lead per million. The salt, which adhered to the glass, was collected by scraping, and found to contain twelve parts of arsenic and 500 parts of lead per million. The bottle was washed; and its inner surface was found to be corroded. The glass of the bottle was analyzed, and yielded 0.34 per cent. arsenious oxide and 31.1 per cent. lead oxide. The salt was a pure potassium carbonate, containing merely traces of chloride, sulphate, phosphate, iron, alumina, and ammonia; it yielded a turbid solution, the insoluble matter consisting largely of silica; the lead and arsenic had been dissolved from the glass. J. S. H.

Removal of Small Amounts of Carbon Monoxide from Gases.—In the arts, traces of carbon monoxide frequently have to be removed from gases, for instance, in order to prevent the poisoning of a catalyst. ROBERT E. WILSON, C. A. HASSLACHER, and E. MASTERSON, of the Massachusetts Institute of Technology (*Ind. Eng. Chem.*, 1923, 15, 698-701), find that small amounts (2 per cent.) of carbon monoxide are removed from nitrogen more efficiently by soda lime of high sodium hydroxide content than by soda lime of low sodium hydroxide content or by lime alone. Using soda lime of high sodium hydroxide content, the carbon monoxide is practically completely removed at a temperature of approximately 400° C. Small amounts of water increase the efficiency of the reaction, but are not essential. The reaction has as its products sodium carbonate and hydrogen.

J. S. H.

New Applications of the Phenol Resins.—According to L. V. REDMAN (*Ind. Eng. Chem.*, 1923, **15**, 677) measuring cylinders and conductivity cells for hydrofluoric acid are made from pure synthetic phenol resins. Laminated products made from these resins are used in the manufacture of barrels and conveyor chains for cyanide plating, valves and their discs in pumps for deep oil wells or for handling corrosive animal by-products, silent gears, buttons, door knobs, mechanical parts on typewriters and adding machines, insulators in the automatic telephone, and parts for radio apparatus.

J. S. H.

THE SHORT-WAVE RADIATION FROM TUNGSTEN FILAMENTS.*†

BY

M. LUCKIESH (Director), L. L. HOLLADAY (Physicist), and A. H. TAYLOR (Physicist).

Laboratory of Applied Science, National Lamp Works of General Electric Company, Nela Park, Cleveland.

VI. ANALYSIS OF THEORETICAL AND EXPERIMENTAL DATA ON PHOTOGRAPHIC ACTINICITIES OF RADIATIONS FROM A TUNGSTEN FILAMENT AT VARIOUS TEMPERATURES AFTER TRAVERSING VARIOUS BULB-GLASSES.

The purpose of this part of the investigation was to study analytically the influences of the spectral sensitivity of the emulsion, the spectral transmission of the bulb-glass and the temperature of the tungsten filament upon the resultant radiations and their effects upon vision and the photographic emulsion.

When given the spectral intensity J_λ of radiant flux in ergs per sq. cm. per second from incandescent tungsten at temperature T, the spectral transmission t_λ of the bulb-glass, the visibility V_λ of the normal eye, then the luminous intensity I in candles per square centimetre can be computed by integrating the product of flux density, transmission, visibility and the element of wave-length $d\lambda$, or

$$I = \frac{1}{\pi M} \int^{\infty} J_\lambda t_\lambda V_\lambda \, d\lambda \qquad (1)$$

where M, the mechanical equivalent of light of maximum visibility, is 15,000 ergs per second per lumen.

By using the definitions and symbols given in Part II, it may be easily shown that when the sensitivity, S, or $\frac{1}{E}$, of the emulsion at standard wave-length 436 mμ, the spectral-sensitivity S_λ for any wave-length λ, the spectral transmission t_λ of the interposed medium and the spectral intensity J_λ of the radiant flux are

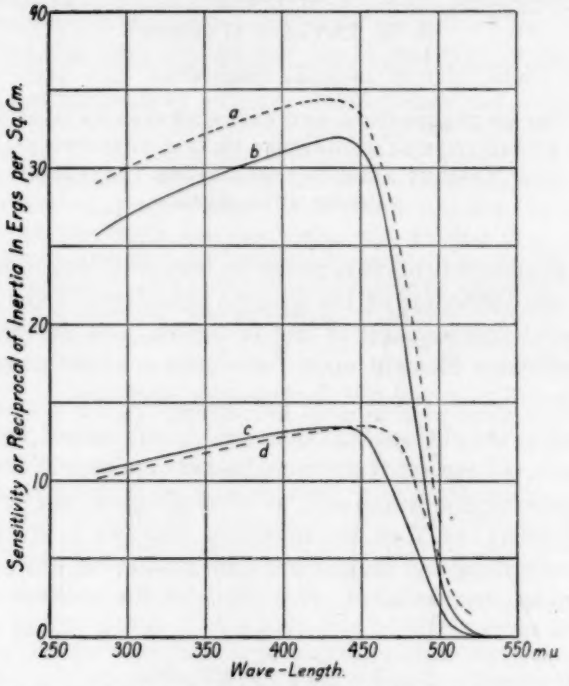
* Communicated by the Director of the Laboratory.

† Concluded from JOUR. FRANK. INST., 196, No. 3, Sept., 1923, p. 373.

known, then the combined efficiency of the transmitting medium and the photographic emulsion is

$$\rho = \frac{\mathrm{I}}{S} \frac{\int_0^\infty t_\lambda S_\lambda J_\lambda \, d\lambda}{\int_0^\infty J_\lambda \, d\lambda}. \tag{2}$$

FIG. 8.



Spectral sensitivity curves of four photographic emulsions: (*a*) Orthonon; (*b*) Seed's 26; (*c*) Seed's 23; (*d*) W. and W. panchromatic.

Similarly, when ρ and S are known the actinicity may be shown to be

$$A = \frac{\mathrm{I}}{E_\tau} = \frac{\rho}{E} = \rho S \tag{3}$$

or when the spectral transmission of the medium, spectral sensitivity of the emulsion and the spectral flux density are known, the actinicity of the radiation may be shown to be

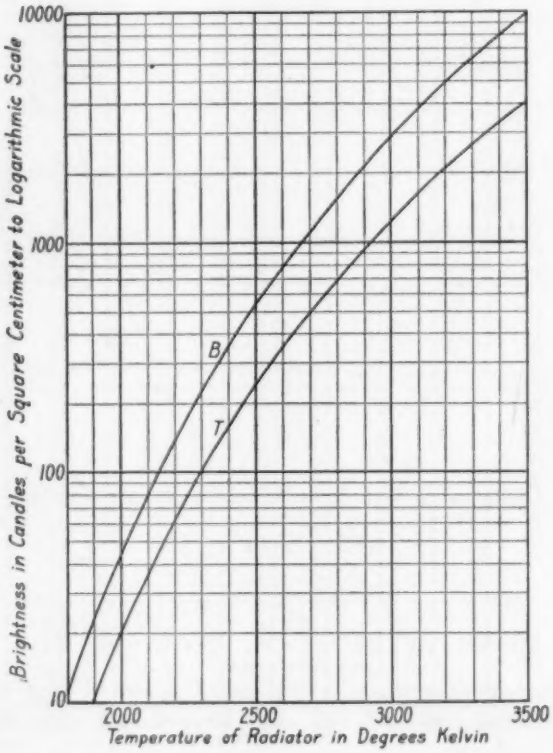
$$A = \frac{\int_0^\infty t_\lambda S_\lambda J_\lambda d\lambda}{\int_0^\infty J_\lambda d\lambda} \tag{4}$$

Also when the spectral transmission of medium, spectral sensitivity of the emulsion and spectral flux density of radiation are known, the photographic effectiveness Q of the radiation may be proved to be

$$Q = \frac{\mathrm{I}}{t} = \int_0^\infty t_\lambda S_\lambda J_\lambda d\lambda \tag{5}$$

or when the sensitivity S of the emulsion at wave-length 436 mμ,

FIG. 9.



Temperature-brightness curves, (*B*) for a "black-body" radiator and (*T*) for tungsten.

the combined efficiency of medium and radiation ρ, and the spectral flux density are known, then the photographic effectiveness Q may be proved to be

$$Q = \frac{\mathrm{I}}{t} = \rho S \int_0^\infty J_\lambda d\lambda \tag{6}$$

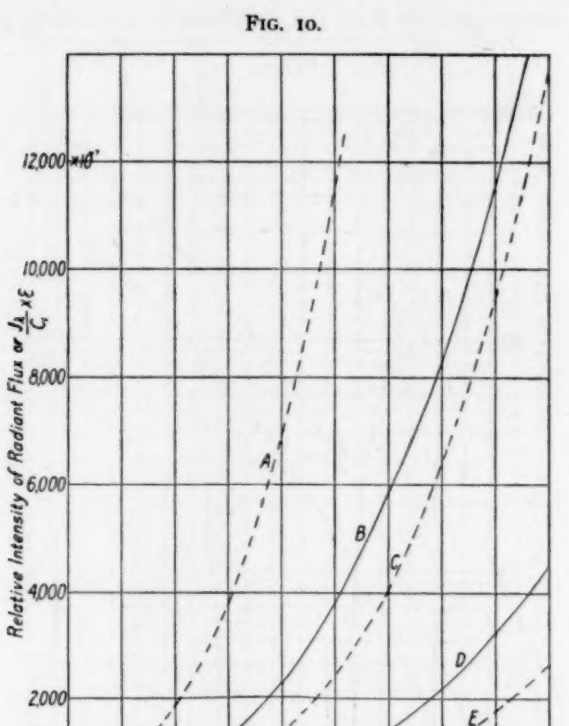
Wien's equation for the intensity of radiant flux from a

black-body at a temperature of $T°$ Kelvin and wave-length λ in μ is

$$J_\lambda = C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}} \qquad (7)$$

where e is the base of the natural system of logarithms and C_1

FIG. 10.



Intensity of radiant flux from tungsten and a "black-body" radiator at various temperatures. Black-body at (*A*) 3600° K., (*C*) 3200° K., (*E*) 2800° K., (*G*) 2400° K. Tungsten at (*B*) 3495° K., (*D*) 3115° K., (*F*) 2735° K., (*H*) 2350° K.

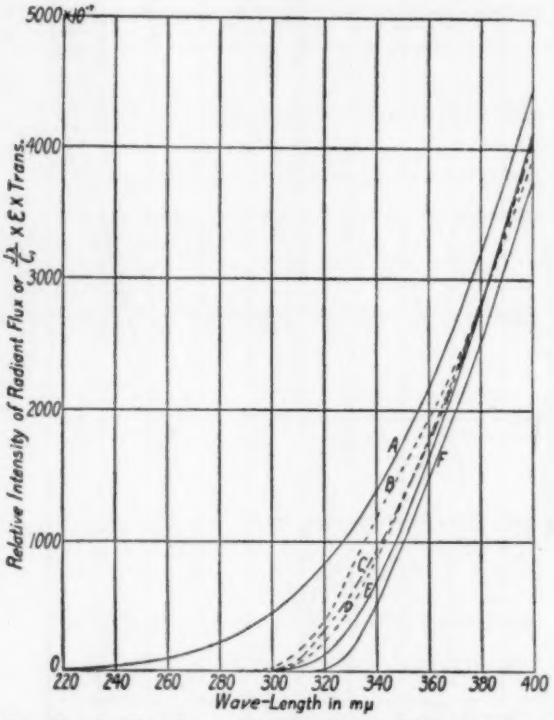
and C_2 are constants. From data presented by Forsythe,[9] Coblentz [10] and others, the value of C_2 is taken as 14,350μ degrees and C_1 as 3.72×10^{-12} watts per square centimetre or as 3.72×10^{-5} ergs per second per square centimetre.

The intensity of radiant flux of wave-length λ for a non-black-body at temperature T is given by the equation:

$$J_\lambda = \varepsilon_\lambda C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}} \tag{8}$$

where ε_λ is a factor defined as the emissivity which is always less than unity. Combining the data of Worthing [11] and of Hulburt [12]

FIG. 11



Spectral intensity of radiant flux from tungsten at 3115° K. (color temperature 3200° K.) through quartz and various lamp-bulb glasses. Through (*A*) quartz, (*B*) soda-lime glass, (*C*) Mazda C-3 photographic glass, (*D*) soda-lead glass, (*E*) boro-silicate hard glass, (*F*) Mazda C-2 daylight glass.

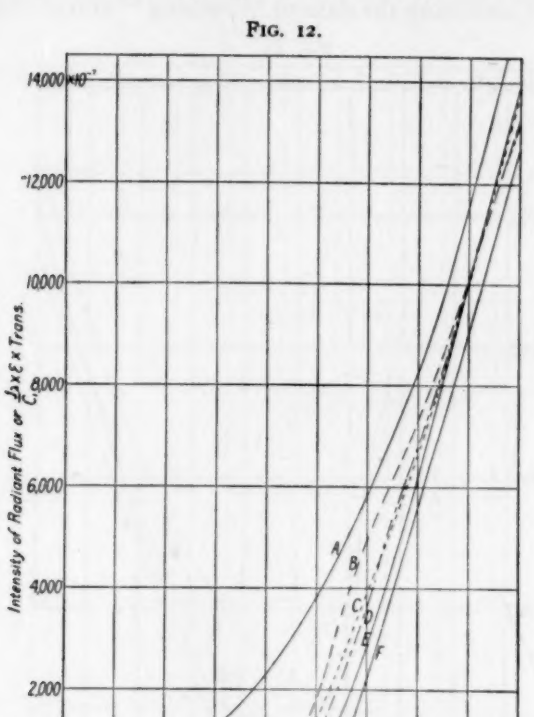
we obtain an empirical equation for emissivity of tungsten for λ in μ and temperature T on the Kelvin scale. This empirical equation is

$$\varepsilon_\lambda = \frac{0.45}{\lambda^{0.2}} - \frac{25}{10^6} T. \tag{9}$$

Values of emissivity computed from this equation are in good agreement with Worthing's data, and with Hulburt's, excepting

in the neighborhood of 580 mμ. The spectral region covered by their experiments was from 340 to 665 mμ. Computed values of emissivities for various wave-lengths are presented in Table III. If this equation for emissivity should be combined with Wien's equation for a black-body, the resulting equation would *probably*

FIG. 12.



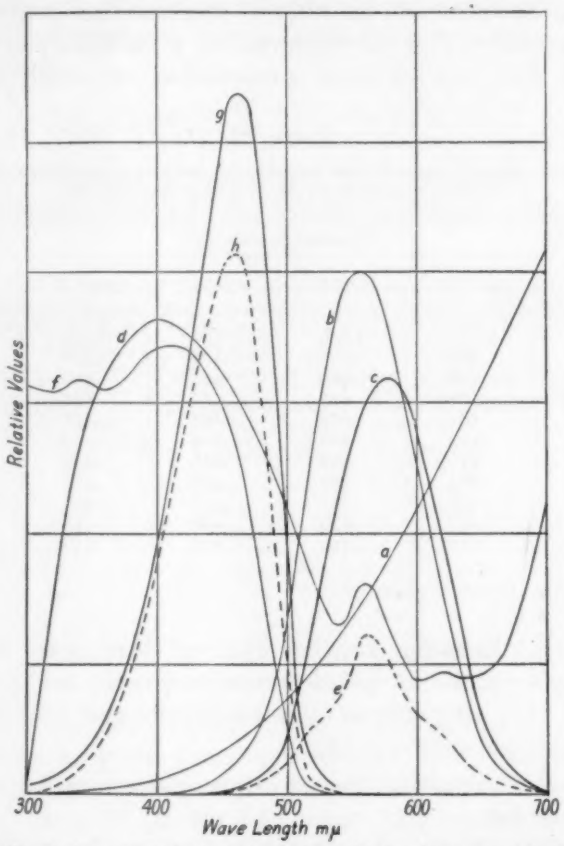
Spectral intensity of radiant flux from tungsten at 3495° K. (color temperature 3600° K.) through quartz and through various lamp-bulb glasses. Through (*A*) quartz, (*B*) soda-lime glass, (*C*) Mazda C-3 photographic glass, (*D*) soda-lead glass, (*E*) boro-silicate hard glass, (*F*) Mazda C-2 daylight glass.

give substantially correct values for the energy distribution for tungsten in the visible and near ultra-violet regions of the spectrum. The equation would then be as follows:

$$J_\lambda = \left(\frac{0.45}{\lambda^{0.2}} - \frac{25T}{10^6}\right) C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}} \qquad (10)$$

The emissivity of a black-body by definition being equal to unity, if the temperature of a black-body is raised to T_c so that the color of the black-body radiation is the same as the color of

FIG. 13.



Curves illustrating various factors entering into visual and photographic effects, and the resultant effects of various factors. (*a*) Radiant flux from tungsten at 2350° K.; (*b*) relative visibility curve of a normal eye; (*c*) relative luminosity of radiant flux from tungsten at 2350°—product of curves (*a*) and (*b*); (*d*) spectral transmission curve of Mazda C-3 photographic glass; (*e*) relative luminosity of radiant flux from tungsten at 2350° K., through Mazda C-3 photographic glass—product of curves (*a*), (*b*), (*c*) and (*d*); (*f*) spectral sensitivity curve of Seed's 23 emulsion; (*g*) and (*h*), photographic effectiveness of radiant flux from tungsten at 2350° K. through quartz and through C-3 photographic glass, respectively.

tungsten radiation when at a temperature T or, if the temperature of the black-body T_c is such that the ratios of brightnesses of the tungsten and black-body are the same for two wave-lengths λ_1 and λ_2, when the true temperature of the tungsten is T, then the

tungsten is said to have a color temperature T_c. Values of color temperatures and true temperatures for tungsten are given in Table IV. These are obtained from data by Worthing,[13] who has also deduced a so-called pseudo-emissive power for tungsten. This may be defined as the ratio of brightness of tungsten at its true temperature T to the brightness of a black-body at temperature T_c, the so-called color temperature, at which the color

TABLE III.

Table of emissivities of incandescent tungsten for various wave-lengths and temperatures computed from the empirical equation (9).

	Computed Emissivities.				
Wave-length mμ.	1500° K.	2000° K.	2500° K.	3000° K.	3500° K.
340	0.521	0.508	0.496	0.484	0.471
380	.509	.496	.485	.471	.458
420	.498	.485	.473	.460	.448
460	.488	.475	.463	.450	.438
467*	.484	.474	.463	.451	.....
500	.479	.467	.454	.442	.429
540	.471	.459	.446	.434	.421
580	.464	.452	.439	.427	.414
620	.458	.445	.433	.420	.408
660	.451	.439	.426	.414	.401
665*	.448	.444	.429	.416	.400

*Values taken from Worthing's data.

of tungsten radiation matches that of black-body radiation. Worthing's values of pseudo-emissive powers are also given in Table IV. Brightnesses of a black-body and tungsten given in this table are shown in Fig. 9.

The pseudo-emissive power of tungsten may be computed from the equation

$$\varepsilon = 0.42 - \frac{25}{10^6} T \qquad (11)$$

where ε is the pseudo-emissive power and T is the true temperature of the tungsten in degrees Kelvin. This equation has been derived from the values of pseudo-emissive power given by Worthing.[13]

Approximate values of the intensity of radiant flux from incandescent tungsten at true temperature T and color tempera-

ture T_c for the visible spectrum and *probably* for the near ultra-violet, may be computed by use of the equation

$$J_\lambda = \varepsilon C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T_c}} \qquad (12)$$

where values of ε, the pseudo-emissive power, are obtained from Table IV or calculated as above. Substituting ε from equation (11), we have

$$J_\lambda = \left(0.42 - \frac{25}{10^6} T\right) C_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T_c}} \qquad (13)$$

Values of intensity of radiant flux for a black-body at various wave-lengths and temperatures have been computed from Wien's

TABLE IV.

Table showing the brightness of a black-body and of incandescent tungsten at various true temperatures, these data being computed by use of values of the brightness of a black-body obtained from data by Forsythe [9] *and pseudo-emissive powers and color temperatures for tungsten as given by Worthing.*[13]

Tungsten.		Pseudo-emissive power of tungsten for wave-lengths .467μ and .665μ	Brightness in candles per sq. cm.	
True Temp. T	Color Temp. T_c		Of black-body at temp. T_c	Of tungsten at temp. T
1200° K.	1211° K.	0.391	0.0158	0.0062
1600	1620	.380	2.57	0.98
2000	2032	.370	54.	20.
2400	2448	.360	437.	157.
2800	2868	.350	1,945.	680.
3200	3292	.340	6,095.	2070.
3600	3720	.329	15,100.	4970.
3675	3800	.328	17,700.	5805.

equation (7) and are given in Table V and plotted in Fig. 10. Values for incandescent tungsten have been computed by use of equation (12) and these are also plotted in Fig. 10. By multiplying the values of radiant flux from tungsten by the transmission-factors of various bulb-glasses 0.8 mm. thick, values of the flux transmitted by the glasses have been obtained for filament temperatures of 3115 and 3495° K., the former being near the practical operating limit of tungsten, and the latter 180° below its melting point. The values are shown graphically in Figs. 11 and 12.

In Table VI are given authoritative values of relative visibility for the average eye. A plot of these data is given on Fig. 13, curve *b*.

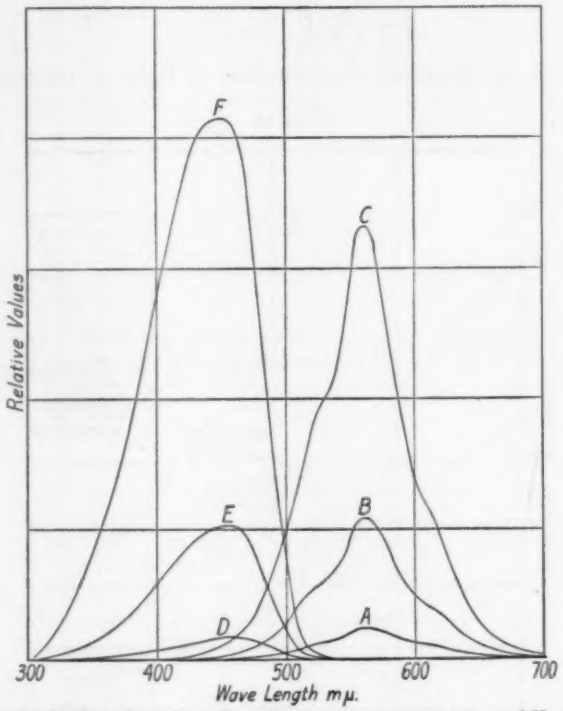
TABLE V.

Relative Intensity of Radiant Flux for a Black-body Radiator Calculated from Wien's Equation.

Wave-length in μ.	Relative intensity of radiant flux or J_λ/c_1.				
	2000° K.	2400° K.	2800° K.	3200° K.	3600° K.
0.22		0.0305×10^{-7}	1.865×10^{-7}	27.25×10^{-7}	262.4×10^{-7}
.24		.140	6.68	96.4	768.8
.26		.866	23.13	271.9	1,848.
.28	0.043×10^{-7}	3.09	65.33	643.9	3,815.
.30	.169	9.09	156.75	1,325.5	6,980.
.32	.545	22.87	331.8	2,445.	11,600.
.34	1.505	50.71	625.5	4,117.5	17,820.
.36	3.65	101.28	1,089.5	6,436.	25,100.
.38	7.96	185.1	1,753.	9,460.	35,101.
.40	15.84	314.7	2,662.8	13,207.	46,100.
.44	50.20	760.6	5,298.	22,720.	70,510.
.46	81.70	1,099.5	7,041.	26,300.	83,760.
.48	126.5	1,528.	9,053.	34,388.	97,100.
.52	267.6	2,669.	13,792.	47,280.	123,250.
.56	495.0	4,190.	19,251.	60,430.	147,150.
.58	646.3	5,079.	22,200.	67,800.	157,800.
.60	824.0	6,046.	25,105.	72,990.	167,520.
.62	1028.5	7,077.	27,900.	79,000.	176,180.
.64	1260.	8,162.	30,982.	84,350.	183,320.
.66	1517.	9,285.	33,650.	88,500.	190,240.
.68	1799.	10,440.	36,600.	92,500.	195,730.
.70	2104.	11,610.	39,346.	96,005.	200,220.
.72	2430.	12,790.	39,800.	99,600.	203,680.
.74	2773.	13,960.	45,150.	102,700.	206,270.
.76	3133.	15,110.	48,000.	105,600.	208,280.

Using equation (1), relative values of luminosity of tungsten through air and through Mazda C-3 photographic glass have been computed for a filament temperature of 2350° K., and plotted spectrally in curves *c* and *e*, respectively, in Fig. 13. In a similar

FIG. 14.



Relative luminosity curves for radiant flux from tungsten at (*A*) 2350° K., (*B*) 2735° K. and (*C*) 3115° K. Relative photographic effectiveness curves for radiant flux from tungsten at (*D*) 2350° K., (*E*) 2735° K., and (*F*) 3115° K.

manner, using equation (5), the relative photographic effectiveness on a Seed's 23 plate has been computed for the radiations from tungsten at the same temperature of 2350° K. for the same media, and are plotted spectrally in curves *g* and *h* on Fig. 13. It may be noted here that actinicities for Seed's 26 and 23 plates computed by this method are in close agreement with the observed values.

In Fig. 14 to the right are shown spectrally the relative luminosity curves for the radiations of tungsten, at three tem-

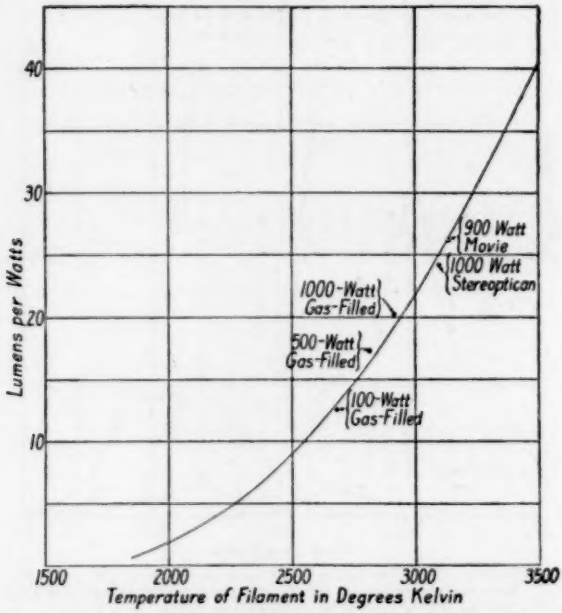
peratures, through Mazda C-3 photographic bulb-glass. Similarly, spectral curves of photographic effectiveness for a Seed's 23 plate, under the same conditions, are shown to the left in Fig. 14.

The brightness B of a black-body at any temperature T may be obtained by evaluation of the integral.

$$B = \frac{1}{\pi M}\int_0^\infty J_{\lambda T} V_\lambda d\lambda \qquad (14)$$

where M is the mechanical equivalent of light of maximum visi-

FIG. 15.

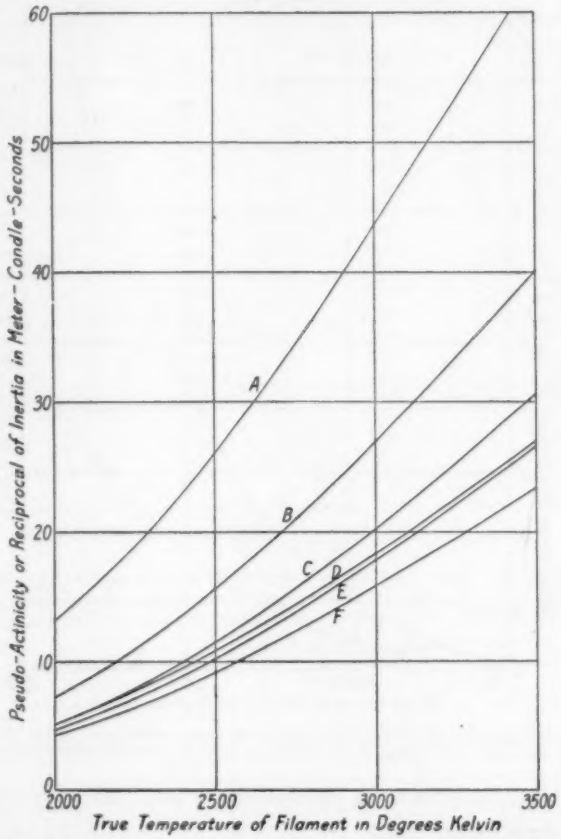


Approximate luminous efficiency (lumens per watt) of gas-filled tungsten lamps at various temperatures.

bility, whose accepted value is .00150 watt per lumen, and V_λ is the relative visibility of radiation as given in Table VI. The brightness of tungsten for temperature T may be obtained by multiplying the brightness of the black-body at the color temperature of tungsten, T_c, by the pseudo-emissive power of tungsten as given in Table IV. Values of brightness for a black-body and tungsten, obtained in the manner described, are given in Table IV and plotted in Fig. 9.

In Table VII are given the brightness and the watts dissipated per square centimetre, and the luminous efficiency of a tungsten radiator at various temperatures in a gas-filled bulb. It is evident

FIG. 16.

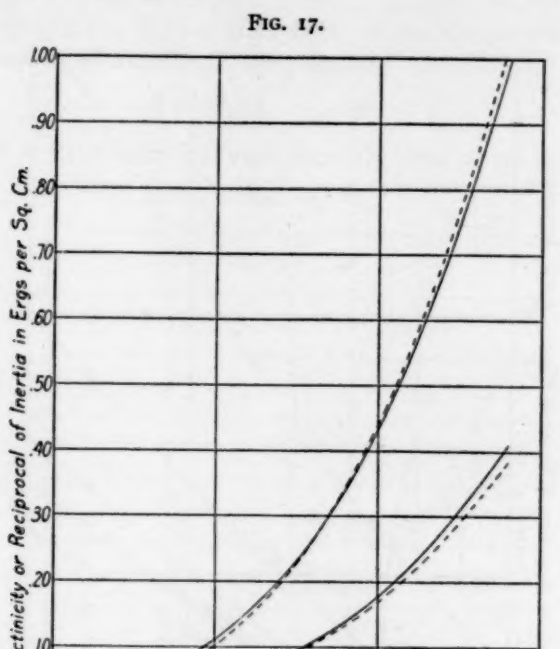


Pseudo-actinicity (1 + inertia in metre-candle-seconds) of radiant flux from tungsten as effective on Seed's 26 plates, illumination being measured at plate position with glass interposed. Interposed media: (*A*) C-3 photographic glass; (*B*) C-2 daylight; (*C*) quartz; (*D*) soda-lime; (*E*) soda-lead; (*F*) boro-silicate hard glass.

that watts dissipated per square centimetre and the luminous efficiency may vary somewhat from lamp to lamp, depending upon its size, the type and pressure of gas, etc.; however, these values for any particular lamp would probably not depart very greatly from the relative values given.

Data on Commercial Lamps.—From published [14] and unpublished work by Hyde and Forsythe, data pertaining to certain representative types of lamps have been obtained. They are given

FIG. 17.



Actinicity (1 ÷ inertia in ergs) of radiant energy from tungsten through quartz, as effective on: (*A*) Seed's 26, (*B*) orthonon, (*C*) Seed's 23, and (*D*) panchromatic emulsion.

in Table VIII, in which the symbols have the following meanings:

lpw = lumens per watt.

T_c = color temperature (Kelvin) of filament, *i.e.*, the temperature of a black-body which gives light of the same color as that from the lamp considered.

T_m = maximum temperature (Kelvin) of any part of filament.

T_a = approximate *average* true temperature (Kelvin) of the filament.

B = approximate average brightness of filament in candles per square centimetre.

It is of considerable importance to know the relative actinicity of radiations from various typical lamps, considered on the basis

TABLE VI.

Table of the relative visibility of radiation for the average eye, as adopted by the American Engineering Standards Committee.

Wave-length in mμ.	Visibility relative to that at 556 mμ.	Wave-length in mμ.	Visibility relative to that at 556 mμ.
400	0.0004	580	0.870
410	.0012	590	.757
420	.0040	600	.631
430	.0116	610	.503
440	.023	620	.380
450	.038	630	.262
460	.060	640	.170
470	.091	650	.103
480	.139	660	.059
490	.208	670	.030
500	.323	680	.016
510	.484	690	.0081
520	.670	700	.0041
530	.836	710	.0021
540	.942	720	.0010
550	.993	730	.00052
556	1.000	740	.00025
560	.996	750	.00012
570	.952	760	.00006

TABLE VII.

Table showing approximately the variation of brightness, watts and lumens per watt of a tungsten filament at various temperatures (Kelvin) in a gas-filled bulb.

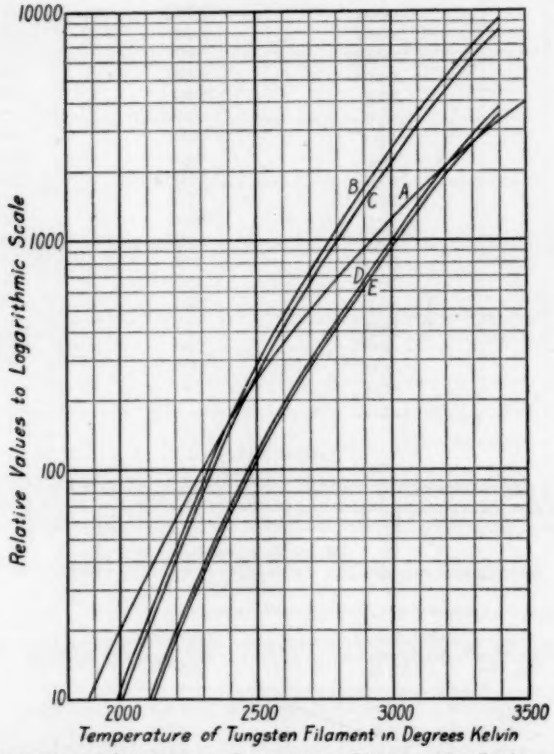
True temp. of tungsten filament in degrees Kelvin.	Brightness of tungsten.		Watts dissipated per sq. cm. of radiator in gas-filled bulb.		Luminous efficiency.	
	Candles per sq. cm.	Relative to brightness at 3000° K.	Per sq. cm.	Relative to watts at 3000° K.	Lumens per watt.	Relative to efficiency at 3000° K.
2000° K.	20.	1.7	35	20.2	1.83	8.3
2200	61.5	5.1	47	27.2	4.1	18.7
2400	157.	13.0	71	41.2	7.1	32.3
2600	352.	29.1	98	56.8	11.3	51.2
2800	680.	56.2	131	76.0	16.1	73.4
3000	1210.	100.	173	100.	22.0	100.
3200	2070.	171.	226	131.	28.7	130.5
3400	3300.	273.	284	164.5	36.5	165.7
3500	4080.	337.	317	183.5	40.5	183.8

of equal watts input. From the tables already given and from other data relative actinicities for the various lamps have been computed. For convenience these actinicities are given relatively

to that for a 1000-watt Mazda C-3 photographic lamp operating at an average temperature of 3000° K., which is approximately its normal operating temperature. These data are given in Table IX.

In Table I, Part III, have been given pseudo-actinicities of the radiations from incandescent tungsten, as measured by four types

FIG. 18.



(*A*) Temperature-brightness curve for tungsten. Photographic effectiveness (1 ÷ inertia in seconds *only*) of radiant energy from tungsten through quartz, as measured by (*B*) Seed's 26, (*D*) Seed's 23 emulsion. Through soda-lead glass, as measured by (*C*) Seed's 26, (*E*) Seed's 23 emulsion.

of photographic emulsions, with various lamp-bulb glasses interposed. In those data the illumination (metre-candles) was measured without the glass interposed, and a deduction of 8 per cent. for reflection by the glass specimen was made. Since the illumination would normally be measured after the radiations have passed through the glass bulb, the data in Table I have been

reduced to this basis, and are presented in Table X. These data for a Seed's 26 plate are also shown in Fig. 16.

Actinicities, or the reciprocals of inertias in ergs per square centimetre of emulsion for radiations from tungsten at various temperatures, are given in Table XI for quartz and for soda-lead

TABLE VIII.

Data Pertaining to Representative Tungsten Lamps.

Type of lamp.	*lpw.*	T_c	T_m	T_a	*B*
40-watt vacuum.....	10	2500° K.	2410° K.	.....	.....
100-watt gas-filled..	12.6	2740	2745	2680° K.	455
500-watt gas-filled..	17.4	2880	2835	2810	695
1000-watt gas-filled.	20.3	2985	3010	2910	930
1000-watt stereopti-can.....	24.2	3175	3185	3095	1575
900-watt movie.....	26.2	3220	3290	3135	1750

TABLE IX.

Table of Relative Actinicities of the Radiations from Various Typical Gas-filled Lamps.

Lamp.	Type of bulb-glass.	Approx. temp.	Relative actinicities of radiations.			
			Seed's 26.	Seed's 23.	Orthonon.	Panc.
100-watt.....	Soda-lime	2680° K.	52	44	49	68
500-watt.....	Soda-lead	2810	70.5	60	69.5	92
500-watt C-2..	Daylight	2810	69	58	65	78
1000-watt.....	Soda-lead	2910	87.5	75	86.5	116
1000-watt stereo-optican.....	Boro-silicate	3095	130	107	119	149
1000-watt C-3..	Photographic	3000	100	100	100	100
900-watt (movie).....	Boro-silicate	3135	143	117	130	163

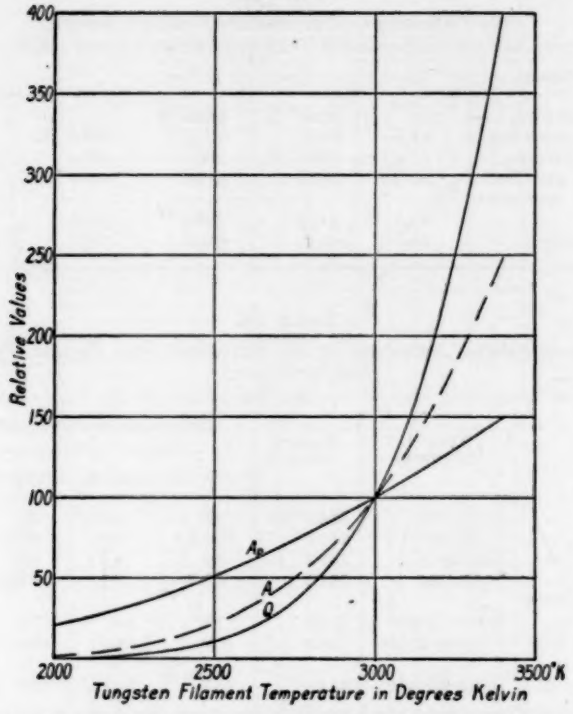
glass. The results for the other clear glasses do not differ materially from these two, but may be easily deduced by anyone interested in them. The actinicities for quartz are also shown in Fig. 17.

The combined effects of increase in intensity and actinicity of the radiant flux with increasing temperature of the tungsten filament are shown by the values of photographic effectiveness (reciprocal of inertia in seconds *only*) tabulated in Table XII. As in Table XI, the data are given for quartz and soda-lead glass

only, but others may be deduced in the manner described. The data for the Seed's emulsions are shown in Fig. 18.

In Table XIII are shown relative values of *pseudo-actinicity*, *actinicity* and *photographic effectiveness* of the radiations from incandescent tungsten at various temperatures. In other words,

FIG. 19.



Variation of actinicity (A), pseudo-actinicity (A_p), and photographic effectiveness (Q) with temperature of the tungsten radiator (Seed's 26 emulsion).

these are the relative reciprocals of inertias in seconds for conditions of constant metre-candles, constant watts and for the total radiant energy, respectively, in terms of their values at a filament temperature of 3000° K. The data for the soda-lead glass and Seed's 26 emulsion are also shown graphically in Fig. 19. These data plotted against lumens per watt are shown in Fig. 20.

In Table XIV and Fig. 21 are given data regarding the rate of change of photographic effectiveness, pseudo-actinicity, and acti-

nicity of the radiations from tungsten for definite temperature and voltage changes. The data are given for soda-lead glass and

TABLE X.

Table of pseudo-actinicities of radiations from tungsten at various temperatures through various bulb-glasses as measured by the four types of emulsions, the metre-candles being measured at the plate with glasses interposed. This table is derived from Table I, Part II, by dividing by one minus the absorption of the bulb-glass specimens.

Type of glass in lamp-bulb.	Pseudo-actinicity or reciprocal of inertias in metre-candle-seconds, the illumination being measured at the plate.							
	2000° K.	2200	2400	2600	2800	3000	3200	3400° K.
Seed's 26 Plate								
Quartz	5.2	7.4	10.0	13.0	16.4	20.1	24.2	28.4
Soda-lead	4.7	6.6	9.0	11.7	14.5	17.7	21.1	24.7
Soda-lime	5.2	7.2	9.6	12.2	15.1	18.2	21.6	25.2
Boro-silicate	4.4	6.	8.1	10.4	13.0	15.8	18.8	21.9
C-2 daylight*	7.2	10.2	13.7	17.7	22.	26.9	32.	37.4
C-3 photographic*	12.6	17.4	23.4	30.3	37.7	46.0	54.6	63.5
Seed's 23 Plate								
Quartz	2.4	3.2	4.2	5.4	6.7	8.1	9.7	11.3
Soda-lead	2.2	3.0	4.0	5.1	6.3	7.7	9.1	10.6
Soda-lime	2.3	3.1	4.1	5.2	6.5	7.8	9.4	10.9
Boro-silicate	2.1	2.9	3.8	4.9	6.1	7.4	8.9	10.4
C-2 daylight	3.1	4.3	5.9	7.5	9.5	11.5	13.8	16.2
C-3 photographic	5.7	8.0	11.1	14.3	18.0	22.0	26.3	30.9
Orthonon Plate								
Quartz	6.4	8.4	10.9	13.6	16.5	19.8	23.4	27.3
Soda-lead	5.2	7.3	9.8	12.5	15.5	18.7	22.3	26.0
Soda-lime	6.2	8.0	10.0	12.4	15.0	17.8	20.8	24.0
Boro-silicate	4.7	6.3	8.3	10.5	12.9	15.6	18.5	21.5
C-2 daylight	8.0	10.9	14.3	18.2	22.5	27.1	32.2	37.3
C-3 photographic	13.7	18.9	24.6	31.2	38.6	46.6	55.2	64.3
Panchromatic Plate								
Quartz	2.3	3.1	4.1	5.2	6.4	7.7	9.1	10.6
Soda-lead	2.1	2.9	3.8	4.9	6.1	7.4	8.9	10.4
Soda-lime	2.2	3.0	4.0	5.1	6.3	7.6	8.9	10.4
Boro-silicate	2.1	2.7	3.4	4.3	5.2	6.2	7.4	8.6
C-2 daylight	3.4	4.2	5.2	6.5	7.8	9.4	11.1	12.8
C-3 Photographic	5.4	6.6	8.0	9.7	11.4	13.7	16.3	18.8

*In computing sensitivities of C-2 daylight and C-3 photographic lamps the average commercial values of transmitted luminous flux of 65 per cent. and 35 per cent., respectively, have been employed.

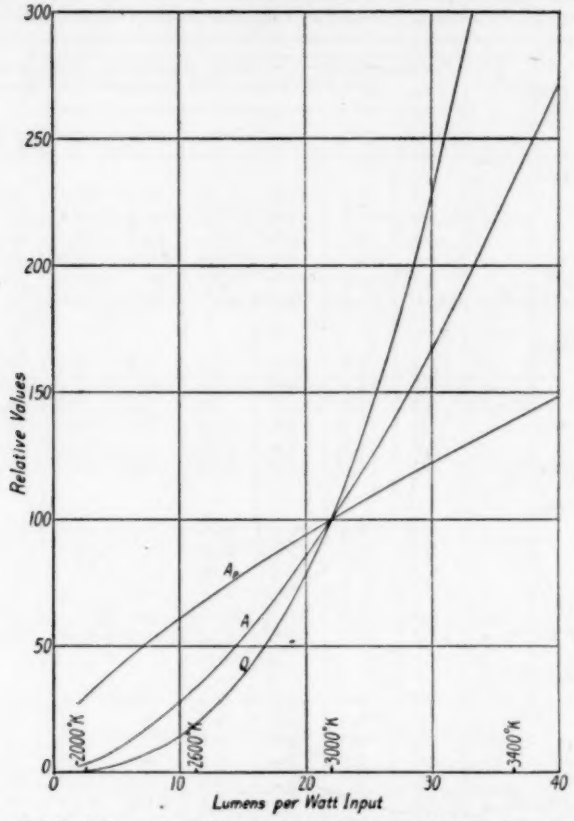
for the Seed's 26 plate only, since they are typical of all plates and glasses tested.

One of the authors has previously found that the transmission factors of colored glasses change with change in temperature. This would probably cause a minor error in our results, when these glasses are incorporated into lamp-bulbs, but the error need not

be taken into account for the glasses considered in this investigation. The error would be very large in the case of red glasses, for example.

The spectrograms of photographic lenses given in Fig. 6 show

FIG. 20.



Variation of actinicity (A), pseudo-actinicity (A_P), and photographic effectiveness (Q) with the luminous efficiency of the tungsten radiator in gas-filled bulb (Seed's 26 emulsion).

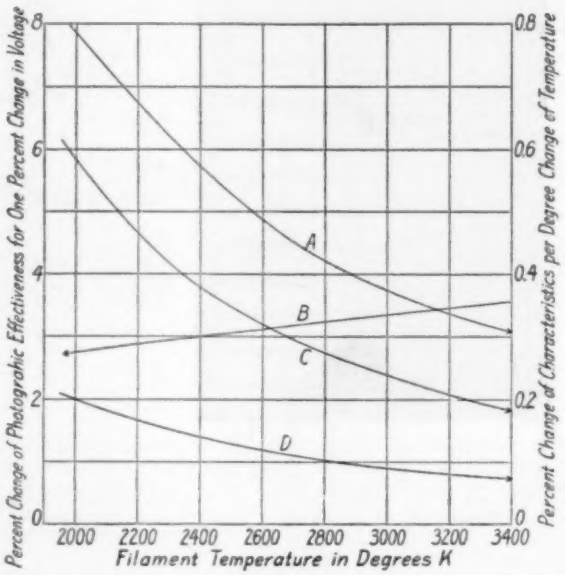
that commercial lenses cut off at a higher wave-length than do the lamp-bulb glasses.

VII. PSEUDO-ACTINICITY OF RADIATIONS FROM THE SUN AND GAS-FILLED TUNGSTEN FILAMENT LAMPS.

The arrangement of photographic apparatus was such that the radiation was first reflected from the plane first surface of a plate

glass, whence it traversed an oscillating three-ply non-selective wire-gauze screen, thence through another similar oscillating wire-gauze screen, thence finally through a ten-step rotating sectored disc to the photographic plate. The plate glass was backed so as to absorb all radiation that traversed the plate and would normally be reflected at the back surface. The illumination was measured at the plate position with the second gauze screen

FIG. 21.



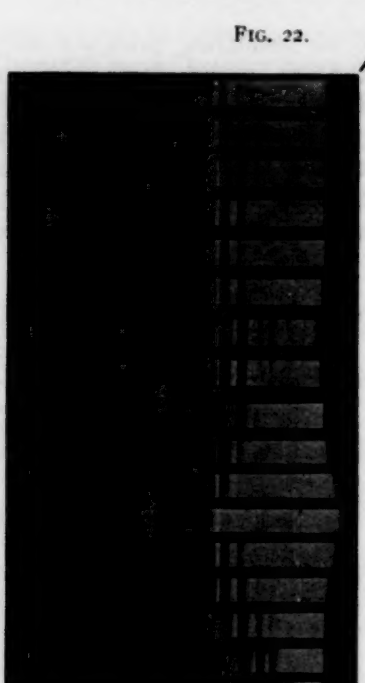
Percentage change in photographic effectiveness (*A*), actinicity (*C*), and pseudo-actinicity (*D*) for 1° C. change in filament temperature; percentage change in photographic effectiveness for 1 per cent. change in lamp voltage (*B*).

removed and the intensity of illumination upon the photographic plate was computed by multiplying the measured value by the transmission factor of the second gauze screen.

The photographic emulsions employed were 4″ × 5″ dry plates manufactured by the Eastman Kodak Company and were of the following types: Seed's 23, orthonon and Wratten M panchromatic.

The three sources of radiation were: a 1000-watt, 115-volt Mazda C lamp; a 1000-watt, 100-volt Mazda C-3 photographic lamp; and afternoon sun between 12.15 and 3 P.M., March, 1921. Results are given in Table XVI.

FIG. 22.



The ultra-violet spectra of the tungsten arc through quartz, at various currents and photographic exposures, as obtained by a quartz prism spectrograph.
(From "Ultra-violet Radiation" by M. Luckiesh.)

TABLE XI.

Table showing the actinicities of radiations from incandescent tungsten at various temperatures as measured by four types of photographic emulsions. These data were computed by multiplying the pseudo-actinicities in Table I by the values of lumens per watt given in Table VII, and dividing by 1000.

Type of plate.	Actinicity of radiations from tungsten at temperatures indicated.							
	2000° K.	2200°	2400°	2600°	2800°	3000°	3200°	3400°
Through quartz optical system alone.								
Seed's 26.....	0.0095	0.0305	0.071	0.146	0.265	0.442	0.695	1.035
Seed's 23.....	.0044	.0132	.030	.061	.108	.178	.279	0.410
Orthonon.....	.0117	.0345	.0775	.153	.266	.435	.675	.995
Panchromatic...	.0042	.0128	.029	.058	.103	.170	.262	.385
Through soda-lead glass.								
Seed's 26.....	0.0086	0.0270	0.064	0.132	0.234	0.390	0.605	0.900
Seed's 23.....	.0040	.0124	.0285	.0575	.101	.169	.262	.385
Orthonon.....	.0095	.0300	.070	.141	.250	.412	.640	.950
Panchromatic...	.0038	.0120	.027	.055	.098	.163	.256	.380

TABLE XII.

Table of relative values of the photographic effectiveness of radiations from incandescent tungsten at various temperatures through two kinds of media for four types of emulsions. These data are computed by multiplying the values of pseudo-actinicity given in Table I by the brightness of tungsten given in Table VII. To obtain absolute values multiply the tabulated values by $10^4 A \div 4d^2$ where d is the distance in cm. from the radiator of A sq. cm. area.

Types of plates.	Relative photographic effectiveness of radiant energy from incandescent tungsten at temperatures indicated.							
	2000° K.	2200	2400	2600	2800	3000	3200	3400° K.
Through Quartz								
Seed's 26	105.6	455	1610	4575	11,070	24,320	50,100	93,700
Seed's 23	48.7	197	676	1901	4,525	9,800	20,080	37,300
Orthonon	130.	517	1755	4786	11,140	23,950	48,450	90,100
Panchromatic	46.7	191	660	1830	4,322	9,320	18,840	34,960
Through Soda-lead Glass								
Seed's 26	95.4	406	1450	4120	9,790	21,420	43,700	81,500
Seed's 23	44.7	185	644	1795	4,254	9,320	18,840	34,960
Orthonon	105.6	449	1577	4400	10,470	22,630	46,160	85,800
Panchromatic	42.6	178	612	1725	4,120	8,950	18,420	34,330

TABLE XIII.

Table showing relative values of pseudo-actinicity A_p, actinicity A and photographic effectiveness Q, for the radiations from incandescent tungsten at indicated temperature (Kelvin) in terms of their values at a filament temperature of 3000° K.

	2000° K.	2200° K.	2400° K.	2600° K.	2800° K.	3000° K.	3200° K.	3400° K.
Relative values for Seed's 26 plates.								
A_p	26.5	37.3	50.8	66.1	81.9	100	119	139.5
A	2.2	6.9	16.4	33.9	60.0	100	155	231
Q	0.45	1.9	6.8	19.2	45.7	100	204	380
Relative values for orthonon plates.								
A_p	27.8	39.0	52.4	66.8	82.9	100	119	139
A	2.3	7.3	17.0	34.2	60.7	100	155	230
Q	0.47	2.0	7.0	19.6	46.3	100	204	380
Relative values for W. and W. panchromatic plates.								
A_p	28.4	39.2	51.4	66.2	82.4	100	120	140
A	2.3	7.3	16.5	33.7	60.5	100	157	233
Q	0.48	2.0	6.8	19.3	46.0	100	206	384

TABLE XIV.

Table showing rate of change of photographic characteristics of radiations from incandescent tungsten through soda-lead glass with definite changes in filament temperature (Kelvin) and voltage, these characteristics being measured by a Seed's 26 emulsion.

Rate of Change in Indicated Characteristics.

Filament temp. ° K.	For one degree change in filament temperature.			Resultant change in photographic effectiveness for 1 per cent. change in voltage.
	Photographic effectiveness.	Pseudo-actinicity.	Actinicity.	
2000	0.79%	0.20%	0.58%	2.75%
2200	.67	.165	.46	2.88
2400	.575	.14	.38	3.00
2600	.49	.12	.32	3.13
2800	.42	.10	.28	3.24
3000	.375	.09	.24	3.35
3200	.34	.08	.21	3.45
3400	.31	.075	.18	3.55

TABLE XV.

Table showing the photographic efficiencies of radiations from tungsten at various temperatures (Kelvin) after traversing various media, as measured by the sensitivities of the Seed's emulsions. These values, in per cent., are computed by multiplying the values of pseudo-actinicities in Table I by values of lumens per watt in Table VII, divided by ten times the sensitivities of the Seed's emulsions for radiations of wave-length 436 mμ given in Part V. Radiant energy of wave-length 436 mμ is taken as standard of 100 per cent. efficiency.

Interposed media.	Photographic efficiencies for tungsten radiation.							
	2000°	2200°	2400°	2600°	2800°	3000°	3200°	3400° K.
Seed's 26 Emulsion	per ct.	per ct.	per ct.	per ct.	per ct.	per ct.	per ct.	per ct.
Quartz	.030	.095	.222	.458	.82	1.38	2.17	3.24
Soda-lead	.027	.085	.200	.413	.73	1.22	1.89	2.81
Soda-lime	.030	.092	.213	.430	.76	1.25	1.93	2.87
Boro-silicate	.025	.077	.180	.367	.65	1.08	1.68	2.50
C-2 daylight	.027	.085	.197	.405	.72	1.20	1.86	2.77
C-3 photographic	.025	.078	.182	.374	.66	1.11	1.71	2.53
Seed's 23 Emulsion								
Quartz	.033	.098	.224	.458	.81	1.34	2.09	3.10
Soda-lead	.030	.092	.213	.432	.76	1.27	1.96	2.9
Soda-lime	.032	.095	.218	.441	.78	1.29	2.02	2.98
Boro-silicate	.029	.089	.202	.415	.74	1.22	1.92	2.85
C-2 daylight	.027	.086	.202	.415	.75	1.24	1.94	2.88
C-3 photographic	.027	.086	.208	.424	.76	1.27	1.98	2.96

TABLE XVI.

Table of pseudo-actinicities of the radiant energy from afternoon sun, a Mazda C gas-filled tungsten lamp at approximately 2850°K., and a Mazda C-3 photographic lamp at approximately 3100°K., as measured by three types of photographic emulsions. Illumination measured at the plate position in all cases.

Type of radiator.	Type of plate.	Pseudo-actinicities.	
		Actual.	Relative.
1000-watt Mazda C	Seed's 23	6.69	.51
1000-watt C-3 photographic	Seed's 23	9.09	.69
Afternoon sun	Seed's 23	13.19	1.00
1000-watt Mazda C	Orthonon	9.13	.56
1000-watt C-3 photographic	Orthonon	14.82	.90
Afternoon sun	Orthonon	16.42	1.00
1000-watt Mazda C	Panchromatic	3.72	.50
1000-watt C-3 photographic	Panchromatic	4.96	.67
Afternoon sun	Panchromatic	7.42	1.00

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[15] *Jour. Amer. Ceramic Soc.*, **2**, 1919, 743; *Trans. I.E.S.*, **17**, 1922, 600.
[16] Since the completion of this manuscript there has come to the notice of the authors a paper proposing certain new photographic units by L. A. JONES, *Illum. Eng.* (London), **15**, Sept., 1922, p. 247. Communication No. 135 from the Research Laboratory of the Eastman Kodak Company.

THE editor of *The Bell System Technical Journal* comments thus on the subject of the first paper in the second number of this periodical "The electric wave-filter, an invention of Doctor Campbell,

is one of the most important of present-day circuit developments, being indispensable in many branches of electrical communication. It makes possible the separation of a broad band of frequencies into narrow bands in any desired manner. . . . As the communication art develops, the need will arise to transmit a growing number of telephone and telegraph messages on a given pair of wires and a growing number of radio messages through the ether, and the filter will prove increasingly useful in coping with this situation. The filter stands beside the vacuum tube as one of the two devices making carrier telephony and telegraphy practicable, being used in standard carrier equipment to separate the various carrier frequencies. It is a part of every telephone repeater set cutting out and preventing the amplification of extreme line frequencies for which the line is not accurately balanced by its balancing network. It is being applied to certain types of composite lines for the separation of the d.c. Morse channels from the telephone channel. It is finding many applications to radio of which multiplex radio is an illustration." G. F. S.

The Lowest Temperature Yet Obtained.—In a communication in the *Transactions of the Faraday Society* (1922, **18**, 145), Dr. Kamerlingh Onnes gives in detail some results recently obtained by him, in which the temperature of liquid helium has been brought to within less than a degree of the absolute zero. The liquefaction of helium having been successfully accomplished, efforts were made to freeze it. The method adopted is that of evaporation under reduced pressure. The initial procedure is with liquid hydrogen. A large volume of this was made, incidental to which operation the preparation of about twice the volume of liquid air was necessary. The helium was converted into a liquid and then allowed to evaporate under favorable conditions, the course of the evaporation being closely watched with care not to cause any elevation of temperature in the liquid. No evidence of solidification was obtained, the liquid preserving its mobility throughout the procedure. Onnes expresses the view that in the experiment he had reached a temperature within less than one degree of the absolute zero, the point being taken as 0.82° K. As a conservative estimate he prefers to give the temperature at some hundredths of a degree below 0.9° K. Onnes considers it possible that helium may not solidify at the absolute zero. However, he calls attention to the fact that other problems in science have been regarded as unsolvable, and yet have been fully solved. Even in this field, the study of which was begun by Faraday, who showed the possibility of liquefying many of the common gases, there was at first a disposition to place certain gases in the "permanent" list, regarding them as incapable of liquefaction, but all these have yielded to patient investigation. H. L.

THE COLORING OF THE DIAMOND BY RADIUM RADIATION.*

BY

S. C. LIND, Ph.D., and D. C. BARDWELL.

THE results of various investigators attempting to color the diamond by radium radiation have not been entirely uniform and in the main were unsuccessful. Doelter [1] classes diamond as the most difficult of all minerals to color, and reports for the most part failures or very slight coloring. On the other hand, Crookes [2] obtained in a few cases bluish-green and sage-green colors and A. Miethe [3] produced a yellow color from a colorless diamond in one instance.

As reported in the preceding paper,[4] all minerals except diamond, that can be colored by radium radiation, are colored by the penetrating (beta and gamma) rays transmitted through the glass tube containing the radium salt. Experiments of this character, using 250 mgs. Ra for thirty days on five Cape diamonds of four to ten carats of bright straw-yellow color, failed in all cases to produce any change in color. Two other cut diamonds of the same color were sealed inside a tube with 10 per cent. $RaCl_2$ for the same length of time. The one which was entirely covered by the 10 per cent. salt became fairly green (about a half grass-green) in thirty days, while the other, lying on the surface of the salt, took on a distinct but fainter green.

It was therefore quite evident that direct (probably alpha) radiation is necessary to color the diamond. This experiment explains why most investigators, working with penetrating radiation only, have failed to produce color changes.[5] To confirm this,

* Communicated by Dr. R. B. Moore, Chief Chemist, U. S. Bureau of Mines and Associate Editor of this JOURNAL. Communication from the Rare and Precious Metals Experiment Station, U. S. Bureau of Mines, in Coöperation with the University of Nevada. Published by permission of the Director, U. S. Bureau of Mines.

[1] C. Doelter, "Das Radium und die Farben," Steinkopff, Dresden, 1910, p. 123.

[2] Sir Wm. Crookes, *Proc. Roy. Soc.*, **74**, 47 (1904); *Nature*, **94**, 300 (1914); *Phil. Tr. Roy. Soc.*, **214A**, 433–45 (1914); *Sci. Amer. Supplement*, No. 2270 (July 5, 1919).

[3] A. Miethe, *Ann. d. Phys.*, 19, 633 (1906).

[4] JOUR. FRANK. INST., September, 1923, p. 375.

[5] Crookes (*loc. cit.*), who obtained positive results, worked with the direct radiation of radium salts.

four straw-yellow Cape cut diamonds of two to six carats were completely covered with 10 per cent. $RaCl_2$, sealed in a glass tube, and left for seventy-five days. A deep grass or sage-green was produced which was of quite uniform shade in all and, as far as could be detected, seemed to penetrate through the crystal. No trace of the yellow color appeared to remain.

The apparently deep penetration of color is very surprising, since alpha rays can penetrate diamond to a depth of the order of 0.001 inch only. This will be more fully discussed later. The non-penetrating character of alpha radiation also led to a second consideration, namely, that alpha rays will be able to reach the surface of the diamond only from those layers of salt immediately in contact with it (from a layer less than 0.001 inch). The rest of the salt absorbs its own alpha radiation and is wholly ineffective in producing any color changes. This suggested that radium emanation could be much more effectively employed, since at low gas pressure, the absorption in a container not too large will be practically negligible, and the proportion of effective radiation will depend principally upon the ratio: $\frac{\text{area of diamonds exposed}}{\text{total area exposed}}$.

Accordingly seven cut diamonds from 1.5 to 9.5 carats, of original color white to yellow, were sealed in a glass tube (about 10 cms. long and 1.5 cms. in diameter) with 114 millicuries (m.c.) initial radium emanation. The fluorescence was marked in all cases but not uniform, varying through greenish-blue to bluish-green shades without reference to the original color of the stones, which were supposed to represent one Brazilian and all the principal South African fields.[6] That the intensity of radiation was greater than in 10 per cent. salt was evident from the increased rate of coloring, though this cannot be accurately judged owing to the rapid coloring of the glass tube container. After an exposure of nine days, during which time 91.4 m.c. of emanation disintegrated, the tube was opened and all seven were found to be colored a moderate shade of green. They were put into another tube of the same dimensions and exposed for nine days to an initial quantity of 161 m.c. of emanation. At the end of this time all had deepened in green shade and were nearly as deep as the ones exposed for seventy-five days to 10 per cent. $RaCl_2$. A third exposure was

[6] Since all the diamonds examined had passed through commercial channels their origin cannot be given with certainty.

begun, but was continued for only a few hours, owing to the cracking of the glass tube. Upon examining some of the diamonds visually it was observed that they had apparently developed "carbon spots."[7] This was very puzzling, as "carbon spots" have never been reported as being produced artificially. The original crystals had been perfect, nor had any "carbon spots" been produced in the four diamonds colored to a deeper shade of green by 10 per cent. $RaCl_2$. Attempts to remove the spots chemically by washing in ammonia, hot HNO_3, hot chromic mixture, organic solvents, etc., failed. Examination under the high-power microscope revealed round black spots like fly specks at a considerable depth below the surface (as much as 1 to 2 mm.), a few of which were surrounded by lighter brown halos as if the "carbonization" process were spreading from a centre.

The rest of the investigation was devoted to an attempt to solve the puzzling problems presented by the coloring and the "carbon spots," in connection with the nature of the latter, and the production of both at depth beyond the range of alpha particles in the diamond.

The coloring itself can be described in a few words. In five specimens of light-yellow cut diamonds no color by penetrating rays (through glass ½ to 1 mm. thick) could be produced in thirty days, as already stated. In more than thirty specimens of cut and one uncut diamond varying in color from colorless to yellow to brown, no failure to produce color by direct contact with radium salt or radium emanation was encountered. Green and only green color was produced; even the shade was the same for the same radiation intensity and the same original color. Prolonged heating to 500° C. restores the *original* color, leaving one to suppose that the green color is superimposed and merely masks the original color.

An estimation of the initial alpha radiation from emanation received per unit surface of diamond, in the experiment where "carbon spots" were first obtained, indicated that the alpha ray intensity was about five-fold that in the case of diamonds buried in 10 per cent. $RaCl_2$, when no spots were developed. Assuming that intensity is the controlling factor, exposure in 50 per cent. $RaCl_2$ ought to produce "carbon spots" also. A test was made

[7] Small specks of carbon, possibly graphite, which frequently are found in natural diamonds.

with four Cape cut diamonds of about two carats each (three white and one slightly yellow) buried in 50 per cent. $RaCl_2$ for seventy-four days. A very deep grass or emerald green color was produced, practically identical in shade in all cases, but no "carbon spots" were produced. In all later experiments it was found that "carbon spots" are produced only in contact with emanation, never in salt, but not universally even in emanation, nor could we determine the factor which controls the carbonization. It was apparently not a characteristic inherent in the individual diamonds, because there were no variations among different specimens under the same conditions; either all or none developed "carbon spots" in a given test. One light yellow cut diamond of eight carats, which developed "carbon spots" in emanation and from which they had been removed (see later), failed to develop any on being radiated with 50 per cent. $RaCl_2$ till it again colored green.

The nature of the spots also remained unsolved. It appeared plausible to suppose that under radiation, diamond, which is known to be an unstable form of carbon at ordinary temperature and pressure, should revert to the stable form graphite, just as white phosphorous has been shown to be converted to red by radium radiation.[8] That such a process might be taking place appeared probable from the brown halos surrounding a few of the spots. To explain the localization of discrete spots, rather than a general darkening similar to that observed by Crookes[9] under cathode-ray bombardment, it appeared plausible to suppose that there exist initial "seeding centres" where the change originates and from which it spreads. This theory was greatly shaken if not entirely upset by the observation that prolonged heating in air at a red glow caused the "carbon spots" to disappear permanently. We can hardly assume a reversion to diamond under these experimental conditions. We cannot attribute it to oxidation unless we assume the diffusion of oxygen into and possibly the diffusion of CO_2 or CO out of the diamond. A very ingenious hypothesis was proposed by Dr. R. B. Moore, namely, that there may be in the diamond minute pockets of CO_2 or CO under high pressure, not detectable by the microscope, which may be decomposed by the radiation into C and O_2 which recombine *in loco* upon heating. CO is the more probable, since CO_2 is very slightly

[8] H. Becquerel, *Comp. Rend.*, **133**, 709–12 (1901).

[9] Sir Wm. Crookes, *Sci. Amer. Supplement*, No. 2270 (1919).

decomposed, even by intense alpha radiation.[10] The depth of the pockets from the surface also imposes a difficulty since they cannot be reached by alpha rays, and beta and gamma rays are much less effective in producing chemical action. This theory also does not conform with the idea of gradual growth (brown halos); some of the spots become large enough to be visible to the naked eye, and all of them are easily visible with a small hand lens. That the spots are in reality some form of carbon is supported by the fact that the simultaneous exposure in emanation of a large number of different transparent minerals, together with the diamond, gave these spots only in the latter.

A most puzzling question is the explanation of any effect, either production of color or of "carbon spots," at a depth in the crystal exceeding the range of alpha rays—if one is to suppose the effect due to alpha rays. The question may be divided into two: (1) Are we sure that the effects are deeper than the alpha ray range? (2) Are they due to alpha rays? (1) There can be no doubt about the depth of the carbon spots below the surface, which were observed by the microscope (change of focus) and confirmed by the diamond-cutter who stated it would be necessary to cut away one-half to two-thirds of the crystals (of several carats) to remove the spots. In regard to the depth of penetration of *color* there is much doubt, and that point will therefore be referred to again. Question (2) can best be considered generally for either effect as follows:

The possibilities of the production of effects beyond the range of alpha rays appear to be the following: (*a*) By penetrating (beta or gamma) rays; (*b*) by soft beta rays which could not penetrate the wall of the glass container, but which do penetrate diamond sufficiently to produce the effects observed; (*c*) by a secondary penetrating radiation set up at the diamond surface by some form of non-penetrating radiation (including alpha rays); (*d*) by transmission by an electronic or atomic "chain effect" of a disturbance set up at the surface, possibly equivalent to (*c*); (*e*) (applying to color only) by the diffusion through the crystal of color produced at the surface. Hypothesis (*a*) can apparently be dismissed by comparing the negative results of exposure outside a tube with the positive ones inside. The possibility of (*b*) is not excluded, but it should be remembered that such soft radia-

[10] E. E. Wourtzel, *Le Radium*, 11, 346 (1919).

tion could not extend the depth beyond a layer equivalent to ½ to 1 mm. of glass, which would be insufficient to penetrate the entire crystal in the case of large diamonds. Regarding (*c*), no such form of radiation in diamond is known, nor would the low atomic weight of carbon indicate that it would have much penetration; on the other hand, not much would be required, for the same reason. Both (*d*) and (*e*) appear intangible at present. None of these hypotheses receives any support from the observations of Joly [11] and of Rutherford [12] on pleochroic halos in mica, which have been shown to have exactly the diameter predicted by the range of alpha rays emitted from a point source, and which have persisted through geological periods of time.

We are therefore forced to leave the question of the penetration of the effects unsettled in regard to "carbon spots" and will conclude the discussion with the observations contained in the following paragraphs on the penetration of color.

As far as can be determined optically (even by gem experts), either with the unaided eye or with the microscope, the color produced in diamonds persists throughout the crystal. On the other hand, this is not consistent with a direct alpha-ray effect, though rigidly it does not need to be, since "carbon spots" are produced by some influence beyond the alpha-ray range and possibly color also. But color production is a much more general phenomenon than that of carbonization and need not be produced by the same radiation. Crookes (*loc. cit.*) found that the removal of the surface from a cut diamond destroys the color. This would appear to show that it is a surface coloring only, but it must be remembered that cutting or grinding a substance of such hardness is a prolonged process involving the generation of much heat, so that the destruction of color may be due to a heat effect.[13]

Two attempts were made to solve the question without cutting or grinding. A small brown cut diamond was colored green by

[11] J. Joly, "Radioactivity and Geology" (1909), pp. 64–9; *Phil. Mag.* (6), **19**, 327 (1910).

[12] E. E. Rutherford, "Radioactive Substances and Their Radiation" (1913), p. 310.

[13] It is interesting in this connection that in 1915, F. P. Mennell (*Mineralogical Magazine*, **17**, 202) described the occurrence of natural green diamonds in an alluvial field situated on the borders of the Somabula Forest in Southern Rhodesia. He states that the color is entirely lost in the usual course of cutting and polishing for use in jewelry.

radiation and then broken into two or three fragments. Examination under a high-power microscope failed to reveal any surface zone of color; each fragment with a colored (polished) surface appeared to be colored throughout, but the reflection and diffraction of green light from the polished (green colored) surfaces was so great that one could not be sure that the appearance of internal color was not merely due to an optical effect. The masking of an internal yellow or brown by green seems to demand more than a thin surface layer of green, but again one must recall that this thin green layer is at polished surfaces from which light is reflected in all directions, and also that the masking is *not* complete in *thick brown* crystals. An uncut chip of colorless diamond was colored green by radiation and then cleaved into two pieces. Viewed through the cleavage plane, the fragment still looked green, but again one could not be sure it was not due to reflection. The question might be settled by covering all the facets but one with foil or paint during radiation, and later covering the colored surface with an opaque covering and looking through the others. This experiment was not attempted.

The question of the color penetration remains unsettled with some evidence in favor of non-penetration, which, however, is not conclusive.

The question of the permanency of the green color to light is a much simpler one. Experiments, both in diffused and direct sunlight, showed that the color is quite permanent, perhaps in the same class with glass colored by radiation, though the observations have not yet extended over so long a period as with glass. This confirms the general rule already stated, that the more difficult a mineral is to color the more permanent the color. As stated, the color can be removed by heating to 500° or higher for half an hour or less (depending on the temperature). In this way green color can be toned down in shade by interrupting the heating at the desired point.

The question of imparting permanent radioactivity to the diamond by radiation by radium, which was the subject of experiments by Sir Wm. Crookes (*loc. cit.*), has not been investigated in the present work, but there seems to be no reason to believe this cannot be explained by "active deposit" (or radium itself in case of contact with radium salt), in the light of adsorption and surface phenomena as now explained by Langmuir and others.

SUMMARY.

1. Diamond is not colored by the penetrating (beta and gamma) radiation from radium salt in glass tubes 0.5 to 1 mm. thick.

2. Diamond is always colored green by direct radiation, either from high-grade radium salts or from the gas, radium emanation. No exceptions were met in more than thirty specimens.

3. The green color is apparently light-permanent, but can be removed by heating to a dull red.

4. Yellow and brown diamonds are also colored green, but are restored by heating to their original colors. In the case of large deep brown stones the color masking by green was not complete.

5. Recutting the crystal after coloring removes the green color. This is possibly a heat effect during cutting, and does not prove that the coloring is merely a surface effect.

6. The depth of penetration of the color zone could not be determined. If it is an alpha-ray effect, it would be limited by the range of alpha rays in diamond, about 0.001 inch. But reflection of green light from the highly polished surface interferes with optical observations.

7. Radiation by emanation is more effective than by salts, owing to the greater absorption of alpha rays by the salt itself.

8. In some cases in emanation, but never in salt, the radiation resulted in the production of " carbon spots " in the interior of the crystal. The black spots are probably a form of carbon, the nature of which was not definitely determined. They can be removed by prolonged heating in a blast flame.

9. The " carbon spots " are undoubtedly beyond the range of alpha rays in the crystals, which suggests that the color may be penetrating also and that both are produced by some form of secondary radiation more penetrating than alpha rays.

Waxy Coating of the Apple. CHARLES E. SANDO, of the Bureau of Plant Industry, U. S. Department of Agriculture (*Jour. Biol. Chem.*, 1923, **56**, 457–468), has studied the constituents of the wax-like coating on the surface of the apple, using Ben Davis varieties. Several hydrocarbons and alcohols were isolated; the chief constituents were triacontane, $C_{30}H_{62}$; a paraffin hydrocarbon, heptacosanol; $C_{27}H_{56}O$, a secondary alcohol, and malol, $C_{30}H_{48}O_2$, a new crystalline dextrorotatory alcohol which contains at least two hydroxyl groups. J. S. H.

AN ANALYSIS OF THE AUTOMOBILE HEADLIGHT PROBLEM.*

BY

P. G. NUTTING, Ph.D.

Consulting Optical Engineer.

FIFTEEN years of active investigation, invention and experimenting have failed to produce safe and efficient means of headlighting automobiles. Scores of different types of headlighting appliances have been produced and are in use, yet the best of these are but little better than the best of fifteen years ago, while the worst is fully as bad as the poorest of that date. Most states have enacted legislation intended to correct headlighting evils but, with one or two exceptions, these have been by no means effective. Meanwhile accidents due to defective headlighting are steadily increasing.

The optical engineers of this country must accept the major share of the responsibility for such a state of affairs. They alone can state when the best possible solution of this difficult problem has been attained. They alone can set limits of tolerance, devise adequate tests and outline specifications and remedial legislation. The driving public is a fairly good judge of efficient headlighting, and the consensus of public opinion is undoubtedly that the problem of headlighting has *not* been solved. The impression is widespread that it cannot be completely solved.

The practical requirements—essential, desirable, and agreeable—of road lighting for safety, convenience, and pleasure have been discussed in dozens of papers and in many reports of committees of the Illuminating Engineering Society and the Society of Automotive Engineers and are familiar to every experienced driver. Means of meeting these requirements have yet received but scant mention, apparently because of a wish to avoid an appearance of commercial bias. The interests of the public, however, demand an impartial, competent analysis of the optical engineering aspects of the problem of headlighting, coupled with

* Communicated by the Author.

specific recommendations as to best practice, tolerances, inspection and safety rules, all from the independent viewpoint of the public itself, regardless of commercial consequences.

AUTOMOBILE HEADLIGHTING REQUIREMENTS.

The safe driving of automobiles at night requires: (1) Beam lighting at a distance ahead on the road, (2) uniform lighting of the driving headway, (3) absence of intense lighting (glare) to the left and above the road in the middle distance.

(1) The beam lighting must be sufficiently intense to clearly illuminate a straight level road 100 to 200 feet ahead, and to clearly pick up pedestrians and unlighted vehicles of a dark shade at a distance of 150 feet. This means a beam candle-power of 5000 to 15,000. Only moderate road curvatures are to be cared for by beam lighting since sharp turns are taken at reduced speed and are lighted at a wide angle by the foreground light.

(2) The foreground lighting must have sufficient spread and intensity for safely negotiating street corners and at the same time light the road straight ahead in the middle distance sufficiently for safe driving. This means an illumination of about a foot candle on the road ahead of the machine with a spread of 15 or 20 feet, shading off laterally in intensity. To produce such lighting there is required some special device intermediate between the parabolic reflector (beam lighting) and the completely diffusing screen as source.

(3) Unsafe glare is avoided by the elimination of high intensities 60 inches above the road and the same distance to the left of the left-hand headlight for a distance of at least 50 feet ahead. This limit of tolerance is usually set at 800 candle-power, about a tenth that within the direct beam. This limit is liberal in view of the optical difficulties of providing a beam with so sharp an intensity gradient at one edge. Good drivers meeting good drivers prefer plenty of light, keep their eyes on the road and away from headlights. Timid and inexperienced drivers passing reckless drivers having illegal or improperly adjusted headlights meet with the greater portion of headlight accidents.

The best headlighting then is that which provides a nearly uniform illumination of about one foot candle (in the driver's line of vision) on the road at all distances from the near foreground to at least 100 feet ahead directly in front of the car and

shading off gradually to right and left and sharply above the horizontal.[1] From two to five times that illumination is probably preferable if glare be carefully eliminated. Less than one-tenth that illumination in either the foreground, middle distance or extreme distance is unsafe in general. On lighted streets, foreground lighting is of chief consequence, on country highways, distant beam lighting.

In practice such ideal headlighting is almost unknown, since very few headlamps are capable of giving it even when carefully adjusted. Instead all sorts of headlighting evils are encountered, most of them far worse than that produced by a simple mirror with plane front glass if properly focused and directed. Undoubtedly the worst evil is the spread beam directed upward by faulty adjustment or bent supports. There is no escape from its dazzling glare while the headway is almost unlighted. A very common defect, occurring with many forms of patented front glasses, is too great concentration of light in the middle distance, frequently combined with too great lateral spread. This means insufficient distant light for safe rapid driving, and, if too widely spread, considerable glare at the critical period of approach. In the headlamps of many small cars no provision at all is made for distant lighting. Other less common headlighting defects are confusing checkerboard light patterns on the road caused by improperly designed prismatic front glasses, and front glass dazzle caused by lens-shaped (spherical or cylindrical) projections on the front glass. Such lens-shaped surfaces, or even rounded corners on prismatic surfaces, of course, should never be tolerated without a visor, for each forms a secondary image of the light source nearly as bright as the source itself, and each image throws light laterally over a wide angle.

PRACTICAL HEADLIGHTING.

Prerequisite in all safe and efficient headlighting are of course a good mirror and a highly concentrated lamp filament, otherwise there can be no control over the direction the light shall take. Fortunately both are available. Metal mirrors spun of soft metal and silver plated are available in a variety of sizes sufficiently perfect in form for all headlighting purposes. Within the past

[1] See report of the Committee on Motor Vehicle Lighting, *Trans. Ill. Eng. Soc.*, Feb., 1922.

two years the headlight lamp problem has also been solved. Lamps are now available having filaments less than $2 \times 2 \times 0.5$ mm., well centred in tipless bulbs. A 2-mm. filament at the focus of a mirror of 1-inch focal length provides an image spread of 12 feet at a distance of 150 feet. This is sufficiently small to permit good beam control and allows some leeway for slight imperfections of mirror and front glass. Lamps with large filaments or bulbs with tips are not to be tolerated. Means of adjusting the lamp in all directions by the driver have not found favor chiefly because their use requires the driver's attention on short turns and changes in grade just when he is most occupied with driving.

In order to secure sufficient distant lighting, roughly 10,000 (5000 to 15,000) beam candle-power must be provided. A lamp with 2-mm. filament in a mirror of 1-inch focal length sends out a beam with a spread of about .0065 steradian. The mirror subtends about 10 steradians, hence a 21 candle-power lamp of proper design can provide about 30,000 beam candle-power—fully double that required. This conclusion may readily be confirmed by a practical test. On the other hand, such a headlamp provided with a highly diffusing front could not give a foot candle of illumination at more than 10 feet away. Obviously beam lighting must be retained in part, the surplus light (about half the whole) being pulled downward to light the middle distance from 10 to 60 feet ahead of the car. The beam proper, with normal spread on a level road, provides the lighting from 50 feet ahead to the horizon. In practice losses by absorption and scatter at the lamp bulb, mirror surface and front glass average perhaps 50 per cent. of the beam.

Foreground lighting may readily be provided in several ways. The immediate foreground is amply lighted (to one foot candle) by light directly from the lamp if not unduly scattered by the front glass. The use of a weakly diffusing (frosted, ribbed or dimpled) front glass gives more light in the middle distance since such glass transmits the bulk of the incident light with but a small deviation. Such glasses can, however, be used only with a visor to obviate glare and waste of light above the horizontal. Front glasses partly covered with small pressed prisms of appropriate angle, base downward, pull part of the beam downward upon the road in the middle distance. The angular deviation

produced by such prisms is roughly half the prism angle, so that the appropriate angles range from 7° to 30°. An angle of 30° is about the greatest feasible in good pressed glass, hence 14 feet ahead of the car is about as near as it is feasible to refract light by means of prisms.

Replacing the ordinary parabolic mirror of the headlamp by an ellipsoidal mirror of proper ellipticity is an efficient and flexible means of securing the proper distribution of light on the road. If the ellipticity is high, the lighting approaches beam lighting with parabolic mirror; if low, the lighting approaches direct lighting from a lamp or highly diffusing source. An ellipsoid having a major diameter about twice the minor diameters gives a good distribution. The lower front quarter is cut away or left unsilvered for the escape of light while the visor effect of the upper front quarter (obviating all glare) is retained.

In principle there are two, and but two, means of avoiding glare: (1) Using an accurately *focused beam* from a clean parabolic mirror and small lamp filament and (2) using the headlamp at the rear end of an opaque *tubular shield*. The first is an ideal to be approached only with high-grade equipment in nearly perfect adjustment. Foreground lighting is provided by a partially prismatic front glass or by using an ellipsoidal departure from the parabolic mirror. The tubular shield (2) may be made as effective against glare as desired, but in practice is made of minimum length, so as not to be ungainly, and the bottom is left open to light the road in the foreground. It thus becomes in effect an enlarged visor of special design. With proper trim and bottom opening, a wide variety of front glasses, giving almost any desired light distribution on the road, is quite feasible.

The three requirements for safe and efficient headlighting may therefore be met by three different types of headlighting appliances as follows:

(*A*) Both headlamps consisting of specially designed ellipsoidal mirrors, each provided with a tipless lamp having a filament not over $2 \times 2 \times 0.5$ mm.

(*B*) Both headlamps consisting of the usual parabolic mirror and housing but provided with special front glasses, each approximately one-half plane and the other half refracting or weakly diffusing or both. If the diffusing type be used, it must be provided with an opaque visor to obviate glare.

(*C*) One headlamp (preferably that on the right) provided with clear glass front and focused for distant beam lighting, while the left-hand headlamp is provided with a prismatic or diffusing front glass and an opaque visor.

Existing headlamps most nearly satisfying all these requirements are chiefly of class *B*. Those of class *A* would be supplied with the car while those of classes *B* and *C* involve but minor, inexpensive parts of the ordinary headlamp assembly readily obtainable. Headlamps of class *A* are appropriate to high-priced, class *B* to medium-priced cars, while those of class *C* are best adapted for use on the lowest priced cars, being quite as efficient but not as attractive in appearance as those of classes *A* and *B*.

ACCIDENT PREVENTION.

The ultimate problem of eliminating accidents due to defective lighting involves much more than a solution of the headlighting problem, namely, the complete elimination of defective lighting. First, the driving public must be educated to know and demand good headlighting equipment kept in adjustment. Again, those driving cars must be taught to avoid directly viewing approaching headlights. An experienced driver, keeping his eyes on his own headway is in little danger from any headlights, however glaring.

Of by far the greatest importance is the setting of definite specifications and tolerances in headlighting performance and providing means for their rigid enforcement by test, adjustment or replacement and penalty for non-compliance. In a few states headlighting laws provide for testing and adjusting stations as well as outlining specifications and tolerances. This is of course the logical procedure since it is the headlighting *performance* not the *equipment* which is correct or at fault. The same equipment may give either very good or very poor headlighting, depending upon its adjustment.

SUMMARY.

The headlighting requirements for safe driving are:

(1) Beam lighting for picking up distant unlighted objects of not less than 5000 nor over 15,000 beam candles, centred on the road between 100 and 150 feet ahead with a maximum spread of not less than 10 nor over 30 feet.

(2) Foreground lighting for the driving headway, short turns and turnouts of not less than 0.1 nor over 5 foot candles from 3 to 60 feet directly ahead, with a spread of at least 20 feet.

(3) Limited lighting in the direction of the eyes of an approaching driver, not over 500 beam candle-power in a direction 60 inches above the road level, 60 inches to the left of the nearest headlight and 60 feet ahead.

Requirements 1 and 3 are met by the combination of the ordinary parabolic mirror, plane glass front and 21 cp lamp with filament not over $2 \times 2 \times 0.5$ mm., well focused. Requirements 2 and 3 are met by the ordinary lamp and mirror provided with either prismatic glass front or diffusing (ground, ribbed or dimpled) glass front with opaque visor or by a combination of all three. Requirements 1, 2 and 3 are all met by any one of three different types of equipment:

(*a*) A pair of headlamps each comprising an ellipsoidal mirror of suitable ellipticity and a lamp having a filament not over $2 \times 2 \times 0.5$ mm., properly focused.

(*b*) A pair of headlamps each comprising an ordinary parabolic mirror, lamp having a filament not over $2 \times 2 \times 0.5$ mm. in the focus of that mirror and a front glass one-third to one-half plane and the remainder either prismatic or weakly diffusing or both, the diffusing portion being covered with a visor of suitable design.

(*c*) One headlamp comprising a parabolic mirror, lamp and plane front glass adjusted for distant beam lighting, the other comprising mirror, lamp, prismatic or diffusing front glass and visor for lighting the foreground and middle distance.

The elimination of accidents due to defective headlighting involves:

Providing proper headlighting equipment and adjustment.

Educating the driving public to appreciate and demand good headlighting and to avoid looking directly at headlights while passing.

Enacting enforcible laws not only setting limits of tolerance in headlighting, but providing for testing and adjusting stations and penalties.

Eliminating the reckless driver.

A Wide Angle Lens for Cloud Recording. W. N. BOND. (*Phil. Mag.*, Nov., 1922.)—A whole hemisphere should be included in the field of view of a lens used to photograph all the clouds in the sky or to record flashes of lightning. A hemispherical lens with its plane surface horizontal and uppermost approximately meets this requirement and forms a sufficiently sharp image on a horizontal plate placed beneath the lens. The lens must be covered by a thin opaque screen having a small circular hole over the centre of the lens. This insures that all rays traversing the lens shall meet the hemispherical surface at right angles. A further improvement is made by covering this screen by a plane plate of glass, which avoids the exclusion from the circular aperture of rays at grazing incidence by the screen, thin though it may be. A monochromatic filter takes care of the chromatic aberration of the lens.

The image formed is circular. Objects at the zenith appear at the centre, while around the circumference are ranged the objects at the horizon. "It may be mentioned that the lens gives views similar to those seen by a fish in water." G. F. S.

Changes in the Charge of an Alpha-particle Passing through Matter. G. H. HENDERSON. (*Proc. Roy. Soc.*, A 717.)—"It is remarkable that investigations on the velocity of alpha-particles have hitherto failed to detect with certainty particles with velocity less than about 8×10^8 cm. per second ($0.4\ V_0$ where V_0 is the initial velocity of alpha-particles from RaCO). Thus the minimum observed energy was that which would be acquired by the alpha-particle falling through about 600,000 volts. It is surprising that particles with such enormous energy should vanish, leaving no trace." The velocity of a beam of the particles was reduced by passage through absorbing material. They were then deflected by a magnetic field and their effect on Schumann photographic plates was registered. They were found to darken the plate when their velocity had fallen to one-fourth of its initial value. An interesting and unexpected product of the experiment was the appearance of a band between the undeflected beam and the beam normally deflected by the field. This is explained as due to alpha-particles with but a single positive charge. The doubly charged particles will turn into helium at some time. The photograph showed in addition the effect of particles with no charge at all. G. F. S.

Fluosilicic Acid.—The fluosilicic acid, H_2SiF_6, of commerce usually contains from 10 to 25 per cent. of the absolute acid, and a product containing more than 30 per cent. of absolute acid has rarely been prepared. C. A. JACOBSON, of Johns Hopkins University (*Jour. Phys. Chem.*, 1923, **27**, 577–580), has devised a method of vacuum distillation by means of which he has prepared a product containing 60.92 per cent. of absolute fluosilicic acid at room temperature 20° to 22° C. J. S. H.

THE ABSOLUTE MOBILITIES OF NEGATIVE IONS IN AIR.*

BY

LEONARD B. LOEB, Ph.D.

National Research Fellowship, University of Chicago.

ALTHOUGH it appears as if the Rutherford [1] alternating current method of measuring the mobilities of negative ions were capable of yielding the greatest accuracy of any of the methods used, the values of the mobilities thus far obtained from it show variations which are far greater than are to be expected from the errors entering into the measurement. Thus in some very careful measurements made in 1910, Kovarick [2] found a mobility of the negative ions of 2.06 cm./sec. volt/cm., while the value obtained by Franck and Pohl,[3] and since then by other workers, generally lay close to 1.8 cm./sec. In the experiments of Kovarick the ions were generated by ultra-violet light acting directly on one of the plates of the field in which the mobilities were measured (Fig. 4a). In order to measure the mobilities of the positive as well as of the negative ions Franck generated his ions in an auxiliary chamber G (Fig. 4b) by means of polonium. The ions were separated by means of a weak field G (termed the auxiliary field) between the plate p and the gauze g and driven through the meshes of the gauze into the alternating field E between g and the plate e. More recently the writer found that the mobilities of the negative ions measured directly on photoelectrically generated (from plate p, Fig. 4a) ions was 2.18 cm./sec., while the mobilities of the negative ions generated by polonium in an auxiliary chamber lay close to 1.84 cm./sec., the conditions otherwise being the same.

Investigation showed that the difference in mobility lay in the use of the gauze and auxiliary field and not in the nature of the ionizing agent, for ions generated photoelectrically from the plate p below the gauze g in Fig. 4b yielded a mobility of 1.87 cm./sec. under nearly the same conditions that gave a mobility of 1.84 cm./sec. with the polonium ions. These experiments indicated

* Communicated by Dr. W. F. G. Swann, Associate Editor of this JOURNAL.

also that the value of the mobility obtained with the gauze varied markedly with the auxiliary field strength as may be seen below.

Polonium Ions.		Photoelectric Ions.	
Field strength in volt/cm.	Mobility.	Field strength in volt/cm.	Mobility.
1.16	1.74	3.26	1.67
2.40	1.84	6.50	1.87
18.9	2.05	13.10	2.04
38.5	2.21		

This variation of the mobility with the auxiliary field strength might be ascribed to an "ageing" effect in the ions. If the formation of the negative ion from an electron takes an appreciable time, then with the *weak* auxiliary field the mobilities will be measured on more mature ions than they would with the strong field. With the fields used above the ages of the ions in the two cases are about 0.35 second at 1.2 volts/cm. and 0.011 second at 40 volts/cm. A change in the mobility of the *positive* ions with age has been observed by Erikson [4] and Wahlin [5] in about 0.01 second. Erikson, however, was unable to detect any such change for the negative ions. Changes in time of from .014 sec. to .073 sec. in crossing the plates with photoelectrically generated ions in some more recent experiments of the writer also showed no change in mobility with age. Finally, if the change in mobility of the ion were due to growth only, then the maximum change observed should be from a mobility of 1.8 cm./sec. to one of 2.18 cm./sec. with the extreme change in fields (*i.e.*, by a factor of 1.21). In another series of measurements from those cited the mobility was found to vary from 1.66 cm. at 1.16 volts/cm. to 2.39 cm./sec. at 97 volts/cm. (*i.e.*, by a factor of 1.44). Thus this explanation is not adequate to account for the phenomenon. An alternative explanation rests on the fact that the mobilities are computed, assuming that the field between the gauze and the plate is given by the potential difference between g and e, and that all the ions start from the plane of the gauze. If, however, owing to the penetration of a strong auxiliary field through the gauze during the negative phase the field strength is greater than that assumed, the mobilities will appear too high. If furthermore, owing to the penetration of the positive phase of the relatively high alternating field through the gauze when the auxiliary field is weak, the ions are cleared from the space near the meshes of the gauze, they will no longer start from the plane of the gauze but from below it.

Thus, the mobilities will appear to be much smaller than they really are. That such conditions actually do exist in experiments using the gauze, and that they can fully account for the magnitude of the effects observed, will be shown in another paper.

The mobilities of the negative ions, as determined by the Franck modification of the Rutherford method, are therefore subject to a grave uncertainty in their absolute value, and one is forced to regard the values obtained with the ions generated directly in the field (Fig. 4a) as being the only correct absolute values that the method is capable of giving. However, the mobilities observed by this method are distinctly above those observed by other methods which, although somewhat discordant among themselves, lie about 1.8 and 1.9 cm./sec. It is impossible to ascribe this difference to any particular cause. There really are only two methods, beside the Rutherford method, which are capable of any great precision. Those are the methods of Zeleny[6] and Langevin.[7] In both these methods the ions are generated as a volume ionization by X-rays. They are thus subject to the uncertainties introduced by:

1. The ill-defined region of the ionized volume from which the detected ions come.
2. The non-uniformity of the volume ionization due to the action of the metal walls.
3. The recombination of ions.
4. The distortion of the electrical fields by the intense ionization produced.

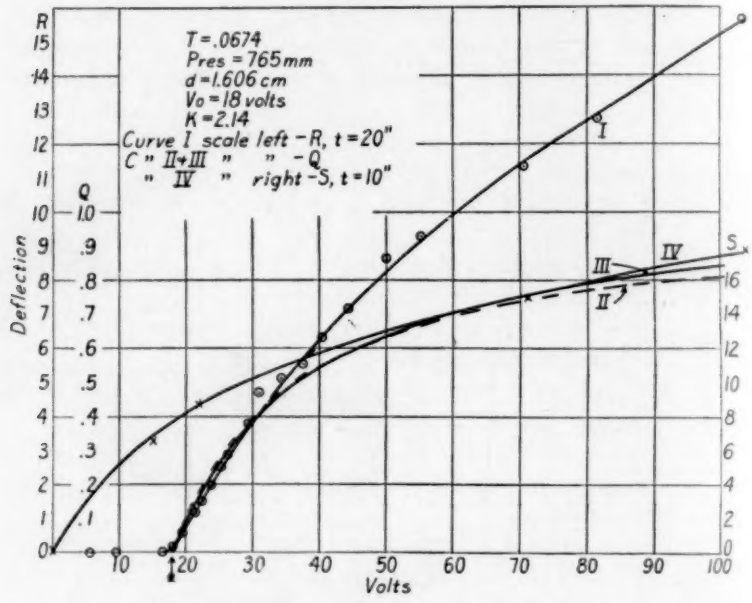
The Zeleny method is furthermore complicated by the unknown conditions of flow of the gas stream and the lack of purity of the large volumes of gases used. While the Langevin method is theoretically free from the complications introduced by the use of X-rays, there may be some inaccuracy in the time intervals between the flash of the X-rays and the closing of the switches, owing to mechanical lags inherent in their operation.

The Rutherford method with photoelectric ions is, however, free from all these uncertainties, for here the ions are liberated from a single plane (*i.e.*, from plate p) just at the instant the negative phase begins. There is no recombination and diffusion does not influence the measurement in the short period in which the ions cross the plates. If the plates are parallel, far removed from the walls of the chamber, and not too far apart, the

field is practically uniform, for the density of the photo ions is too small to produce an appreciable effect. The timing produced by the commutator is free from mechanical lags and any error produced by a single phase is averaged out in the hundreds of phases over which the ions are collected.

The mobility observed by this method may, however, be challenged on the ground that since the ion leaves the plate as an

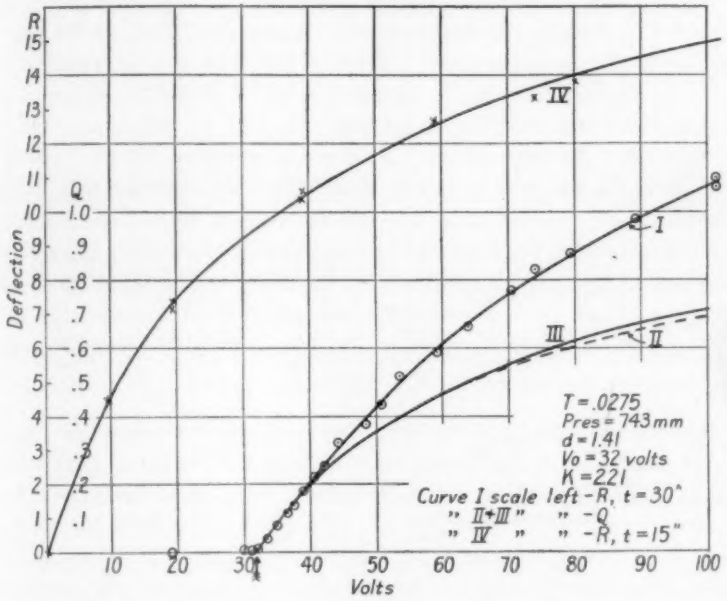
FIG. 1.



electron, the whole process of formation of the ion must occur while it is crossing from p to e, and hence the mobility is not that of a fully formed ion. This formation must first consist in the attachment of an electron to a molecule or an atom. This ion may then further grow by adding on several more molecules. The further growth of the ion seems rather doubtful in view of the fact that Erikson did not observe any change in mobility corresponding to such a growth, and in view of the fact that the electron with its intense field of force shows such a reluctance to attach to a single molecule, that it seems highly doubtful if this molecular ion with its weaker field of force could attach any more molecules. Con-

cerning the distance which the ion travels in the field in its initial electronic stage, we have some definite information. In a later paper the mobilities of electrons in air below 100 mm. will be given. It will there be seen that above this pressure electron mobilities in air are essentially constant and equal to about 1500 cm./sec. The average distance Δ which an electron moves in a field X before attaching to a molecule is then $\Delta = K'nXt$, where n is

FIG. 2.



the average number of impacts with air molecules necessary before an electron can attach ($n = 2 \times 10^5$), K' is the electron mobility, and t is the time an electron spends between impacts. The quantity t may be evaluated from the ratio $L/\bar{c}$ (mean free path divided by the velocity of agitation), which we obtain from the well-known equation of Townsend, $K' = \frac{.815}{300}\frac{e}{m}(L/\bar{c})$. Thus $\Delta = (K')^2 \frac{300mnX}{.815e} = 6.8 \times 10^{-16} (K')^2 \times n$. Under the most extreme experimental conditions used, $x = 50$ volts/cm., and hence $\Delta = 0.15$ cm. As the plate distance here was 1.6 cm. the ions travelled 1 per cent. of this distance as electrons in a very short time. Thus they did not start as ions at the plate p, but at a distance

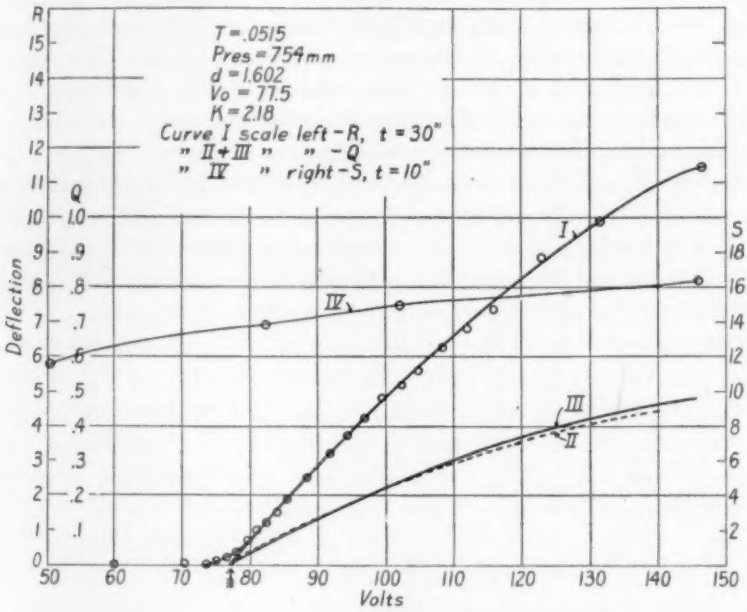
.015 cm. above it. The mobility obtained would therefore be 1 per cent. too high. If the assumption be made that the extrapolation of the electron mobilities at 100 mm. was not justified, and if we assign to the electrons a mobility $K' = \frac{152{,}000}{21.5 + V}$, which leads to a normal electronic mean free path in air, the error introduced would be at most 1.5 per cent.

The existence of appreciable values of Δ would make themselves evident experimentally by changes in mobility with the value of X, and by the appearance of asymptotic feet at the intercept with the voltage axis. Within the limits of experimental error no certain change of mobility with X could be detected in the measurements with fields between 12 and 50 volts/cm. Below 50 volts/cm. the asymptotic feet were in general absent. At this field strength the feet began to make their appearance to a slight extent (Fig. 3). Finally, as will be shown in a future paper, if we assume that the ions have a *unique mobility constant* and that the ions all start from the level of the plate at the opening of the negative phase (*i.e.*, that $\Delta = 0$) the current to the electrometer at a given voltage V relative to the maximum possible current may be expressed by the relation $I/I_0 = \frac{V - V_0}{V}$; where V_0 is the voltage at which the ions are just able to cross the plates. If the experimental conditions are fulfilled, then the experimental values of I/I_0 should coincide with those computed from the above equation, using the value of V_0 observed. As may be seen in Figs. 1, 2 and 3, curves III (experimental) and II (computed), the curves coincide within the limits of accuracy of the measurements. Although too much significance must not be placed on the coincidence of the curves, the foregoing permits one to conclude that the electronic origin of the ions does not increase the mobility observed by this method by more than 2 per cent. with the field strengths used.

The two ion chambers used in these experiments have been described elsewhere.[10] The plates p and e were housed in large earthed metal cases in which the walls were at least 7 cm. from the plates. Two sources of photo electrons were used. One was a brass plate and the other a speculum metal plate which were illuminated at grazing incidence by the image of a Heræus quartz mercury arc focussed on them by a quartz lens of 4 cm. aperture

and 30 cm. focal length. The plates were insulated from the base by a glass block 5 cm. in diameter and 4 cm. high. Above the plates, suspended from a threaded brass rod, insulated by amber, was the upper plate *e*, or electrometer plate. By means of a soft iron lug on the brass collar above this plate the plate could be raised or lowered on the threaded brass rod by an electromagnet from outside the housing. This arrangement unfortunately made

FIG. 3.



it difficult to obtain strict parallelism of the plates. The plate distance was measured by a cathetometer which also permitted the lack of parallelism to be determined. When the plates were not parallel, the average distance between them was usually taken. The plates had a diameter of 9.5 cm. in one case and of 10 cm. in the other, and were used with plate distance between 1.4 and 2 cm. only. Thus the fields were fairly uniform. The alternating field came from a two-segment commutator 8 cm. in diameter with the segments separated by a 2 mm. gap of ebonite. This was driven by a motor whose speed could easily be maintained constant within 1 per cent. over periods of two to three hours. The fre-

quency was changed by changing the gear ratio between the commutator shaft and the motor. The P. D. between the plates was furnished by a bank of Columbia dry cells and was read on a Weston D. C. voltmeter. The voltmeter reading was converted to the true potential across the commutator by comparing it with the reading given by a carefully calibrated Kelvin static voltmeter. Owing to the fact that while measurements were being made the P. D. from the commutator acted across the capacity formed by the plates and the capacity of the shielded leads to the electrometer connected in series, the actual P. D. across the plates was less than the applied potential. A correction was made for this by evaluating the capacities involved. The capacity of the leads was very close to 100 cm., while the capacity across the plates varied from 6 cm. to 3 cm. as the distance between the plates was varied from 1 cm. to 2 cm. The correction which lay between 3 per cent. and 6 per cent. was then deducted from the converted voltmeter readings to give the true P. D. acting across the plates. The chambers were closed off without the use of grease or wax and the air used was carefully dried by passing over NaOH, $CaCl_2$, two tubes of P_2O_5, and through a trap cooled to $-100°$ C. by frozen alcohol.

The measurements were taken over a period of two hours' time, the arc being maintained at a constant potential of seventy volts within 1 per cent. during the readings. Under these conditions the photoelectric emission remained essentially constant with the speculum metal plate, while with the brass plate a photoelectric fatigue was observed. This could be corrected for by control reading taken at the beginning and end of the measurement, since the time of each intermediate reading was recorded. In any case this fatigue effect was less than 10 per cent. Each point on a mobility curve was the average of two electrometer readings at a given voltage. Where the two readings differed widely, more readings were taken until a concordant value was reached. Near the critical voltage the readings were taken in 1.5 volt steps. Readings were taken with descending and then ascending values of the potential. At the end of a series of readings the motor was shut down and the measurement of the saturation current was made, the ions being collected over but half the time interval in which they were collected with the alternating current (for with the alternating current the negative phase was on but half the

time). Samples of typical curves obtained are shown in curves I, Figs. 1, 2 and 3. The curves, labelled II and III, are the I/I_0 curves, III being the observed curve, and II being the one calculated from theory, while curves IV are the saturation curves.

As may be seen, the mobility curves are smooth curves making comparatively sharp intercepts with the voltage axis. These curves are typical of all the curves obtained by the writer in the course of four years' work with this type of apparatus. In no case, no matter how carefully the air was dried, has he ever observed the fantastic and irregular mobility curves recently obtained by Nolan[8] with this method. Curves obtained using a gauze and auxiliary chamber with polonium as a source of ions also failed to show any more irregularities than those shown here. It is the writer's impression, based on long familiarity with this method, that the results of Nolan[8] and of Haines,[9] who use the Rutherford method, are irregular because of failure to observe some of the fundamental conditions which must be fulfilled in order that proper results may be obtained. In the experiments of Haines the difficulty is perhaps due to the great plate distances used and the near proximity of the glass walls of his ion chamber to the plates. Thus the fields produced cannot be uniform. Owing to the lack of details in Nolan's description of his apparatus, it is impossible to state the possible cause of his irregularities.

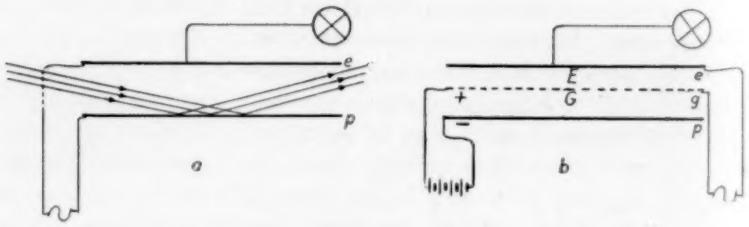
The value of the mobility obtained in fields varying from 12.5 volts to 50 volts/cm., in frequencies varying from 14 cycles per sec. to 75 cycles per sec., and with plate distance lying between 1.4 and 2 cm. at 760 mm. pressure, may be summarized as follows:

Old Ion Chamber Corrected for Lack of Parallelism.	New Ion Chamber Slightly Non-parallel, not Corrected.	New Chamber Quite Parallel.
2.21	2.24	2.14
2.26	2.22	2.18
2.24	2.20	2.14
2.19	2.15	2.23
2.20	2.205 Ave.	2.17
2.19		2.17 Ave.
2.20		
2.20 Ave.		

Weighting the three groups 1, 2 and 3 on the basis of their relative merit, due to parallelism, we get as an average value of

the negative ion mobility the value 2.18 cm./sec. volt/cm. The greatest uncertainties lie in the evaluation of the plate distance where the plates are not quite parallel. This introduces an uncertainty of ± 3 per cent. The estimation of the voltage intercept is not certain to better than .3 volt. At a value of V_0 of 15 volts this makes a possible error of ± 2 per cent. Errors of ± 1 per cent. due to timing, of from 0 to + 2 per cent. on account of the distance gone as an electron and perhaps of ± 2 per cent. in the conversion and correction of the potentials between the plates must also be considered. Taking into account the variety of conditions under which these results were obtained, one may

FIG. 4.



safely place the mobility of the negative ion as 2.18 ± .04 cm./sec. volt/cm. in place of the value of 1.8 cm./sec. usually assigned to it.

In conclusion the writer desires to acknowledge his indebtedness to Mr. Lloyd Smede and Mr. R. A. Loveland for their assistance in making some of the measurements.

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NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

APPLE BY-PRODUCTS AS STOCK FOODS.[1]

By G. P. Walton and G. L. Bidwell.

[ABSTRACT.]

As only a small part of the moist apple pomace produced each year by cider and vinegar makers can be profitably utilized in the fresh condition or ensiled, its preservation by dehydration is recommended.

Because of its property of absorbing large quantities of water, dried apple pomace is made and used as a source of succulence for the winter feeding of dairy cows. Pound for pound of dry matter consumed, the moistened pomace seemed to be slightly more efficient as a milk producer than corn silage.

Dried apple-pectin pulp, the dried material remaining after the extraction of sugars, pectin, and other water-soluble substances from apple products, seemed to be intermediate between corn silage and beet pulp as a source of succulent feed for cows.

The valuable extractives of apple pomace, sugars and pectin, are utilized as ingredients of food for human beings. All surplus apple pomace should be dehydrated and, together with other suitable apple residues, used as stock food.

SUITABILITY OF VARIOUS SOLVENTS FOR EXTRACTING VANILLA BEANS.[2]

PART 1.

By J. B. Wilson and J. W. Sale.

[ABSTRACT.]

BECAUSE of the restrictions on the use of alcohol which have followed prohibition, and the consequent substitution of other solvents for extraction of flavors, some preliminary work has been done to determine whether or not these alcohol substitutes

* Communicated by the Chief of the Bureau.

[1] Published as *U. S. Dept. Agr. Bul. 1166*, July 26, 1923.

[2] Published in *Ind. Eng. Chem.*, **15**, (Aug., 1923): 782.

produce the same quantity and kind of extracts as those prepared from ethyl alcohol. The investigation was limited to several varieties of vanilla and tonka beans, and the solvents selected were isopropyl alcohol, ether, acetone, and carbon tetrachloride, to be compared with ethyl alcohol. The results show that the alcoholic solvents are much superior from the standpoint of quantity of extraction, the carbon tetrachloride being the poorest in this respect. It is possible, however, that a preliminary extraction with ether or carbon tetrachloride, followed by a weak alcoholic solution, may be found practicable.

PRODUCTION OF SYRUP FROM SWEET POTATOES.[3]

By H. C. Gore, H. C. Reese, and J. O. Reed.

[ABSTRACT.]

A METHOD for the commercial manufacture of sweet-potato syrup, based on laboratory and plant experimental work, has been developed by the Bureau of Chemistry. From the standpoint of quality, this syrup has possibilities for use as a table syrup, for cooking purposes, and in the manufacture of colored and short-grain candies. For baking purposes it might find a use in dark products, such as ginger snaps. It also has properties which make it suitable for use in blending with other syrup to prevent crystallization.

The commercial possibilities of sweet-potato syrup are limited by the high cost of manufacture under the present method.

EFFECT OF DIALYSIS ON DIRECT CRYSTALLIZATION OF CITRIC ACID FROM LEMON JUICE.[4]

By H. D. Poore.

[ABSTRACT.]

PRELIMINARY experiments using collodion sacs in dialyzing lemon juice, followed by dialysis on a large scale in an osmogene containing collodion-impregnated cloth membranes, gave the following results:

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[3] Published as *U. S. Dept. Agr. Bul. 1158*, July 3, 1923.

[4] Published in *Ind. Eng. Chem.*, **15**, (Aug., 1923) : 773.

(1) The small quantity of colloids present in lemon juice does not affect crystallization, but the ash and other non-acid constituents prevent satisfactory crystallization of concentrated fermented juice.

(2) In the presence of ash and other impurities, needle and leaflet modifications of citric acid crystals are obtained; upon the removal of half of the ash, characteristic citric acid crystals are formed.

(3) At the concentration necessary for crystallization, the mother liquor is so viscous that the crystals cannot be separated.

THE SPECTROPHOTOMETRIC IDENTIFICATION OF DYES.[5]

I—ACID DYES OF THE PATENT BLUE TYPE.

By Walter C. Holmes.

[ABSTRACT.]

THE degree to which the intensity of the absorption of solutions of dyes is modified by variations in concentration, solvent, alkalinity, acidity, and other conditions, depends upon the degree of alteration of the dye in molecular form or aggregation, which, in turn, depends upon constitutional differences. The quantitative measurement of intensity of absorption under such variation in conditions, accordingly, affords spectrophotometric ratios, or constants, which have important diagnostic value for purposes of identification.

In the analytical scheme for the identification of acid blues of the Patent Blue type outlined, such spectrophotometric ratios are employed to supplement the spectroscopic data customarily obtained. A comprehensive table of constants for the identification of the dyes in question is supplied.

Heat of Vaporization of Mercury and of Cadmium.—These constants of nature have been determined by MAYOR F. FOGLER and WORTH H. RODEBUSH, of the University of Illinois (*Jour. Am. Chem. Soc.*, 1923, **45**, 2080–2090). The heat of vaporization of mercury is 14670 ± 50 cal. at 298.1° K., that of cadmium 25350 ± 100 cal. at 594.1° K. J. S. H.

[5] Published in *Ind. Eng. Chem.*, **15**, (Aug., 1923): 833.

Recent Contributions of Chemistry to Medicine are discussed by ERNEST H. VOLWILER (*Ind. Eng. Chem.*, 1923, **15**, 906–910). Certain dyes, such as acriflavine, mercurochrome and mercurophen, have found application as bactericides and antiseptics. Acriflavine, also known as trypaflavine, is characterized by the unusual property of more marked bactericidal action in the presence of serum than in its absence. Mercurochrome and mercurophen are aromatic compounds in which mercury is attached directly to the benzene nucleus. Of the aromatic derivatives of arsenic, mention should be made of arsphenamine, neoarsphenamine, sulpharsphenamine and tryparsamide, which are used to combat diseases produced by certain minute animal parasites known as spirochetes and trypanosomes. The synthetic hypnotics and sedatives are derived from urethane, the sulphones, ureides, and closely related compounds. Epinephrine or adrenalin, the hormone which is secreted by the suprarenal glands and raises the blood-pressure, has been synthetized on a commercial scale. Thyroxin, the hormone which is secreted by the thyroid and governs the basal metabolism of the body, has been isolated in the pure state. Chaulmoogra oil, which is obtained from the seed of a tropical tree, contains two acids, chaulmoogric and hydnocarpic acids, which are characterized by the presence of a five-membered carbon ring. The esters and salts of these acids are of great value in the treatment of leprosy. J. S. H.

Elimination of Carbon Monoxide from Blood.—The most important factor in the treatment of cases of carbon monoxide poisoning is the early elimination of the carbon monoxide from the blood. R. R. SAYERS and W. P. YANT (*Public Health Reports*, 1923, **38**, 2053–2074) have made an exhaustive study of the use of air, oxygen, and a mixture of carbon dioxide and oxygen in the treatment of such poisoning. They draw the following general conclusions: Recovery depends to a great extent upon early elimination of the carbon monoxide from the blood. The rate of elimination depends on the percentage of oxygen in the inspired air and on the rate and depth of respiration. When a person has been gassed to such an extent that 35 or 40 per cent. of the hemoglobin of the blood has combined with carbon monoxide, administration of pure oxygen causes the elimination of the carbon monoxide to proceed four times as rapidly as in normal air. If 8 to 10 per cent. of carbon dioxide be added to the pure oxygen prior to its administration, deep and rapid respiration is produced, and the carbon monoxide is eliminated five to six times as rapidly as in normal air. Every victim of carbon monoxide poisoning not under a physician's care should be caused to breathe oxygen in the purest available form for at least 20 to 45 minutes. It is also recommended that physicians treat the poisoning with the mixture of oxygen and carbon dioxide whenever possible; otherwise they should use pure oxygen. J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.*

PREPARATION AND DETONATING PROPERTIES OF CYANURIC TRIAZIDE.

By C. A. Taylor and Wm. H. Rinkenbach.

THE detonating compound cyanuric triazide was discovered and patented by Erwin Ott. The Bureau of Mines has determined its properties at request of the Bureau of Ordnance, U. S. Navy.

Pure sodium azide was dissolved in a slight excess of water, and an equimolecular weight of cyanuric chloride was added. The reaction is exothermic, and the temperature rose to about 45° C. The cyanuric chloride was disintegrated as much as possible under the water, and the mixture was allowed to stand for at least twelve hours to insure complete reaction. The solid product was then filtered off and washed with distilled water, and finally dried and weighed. The yield was 90 per cent. of the theoretical, and the product melted at 94° C. The crystals were pure white and very uniform, averaging 0.1 mm. in length. The longest found was 0.3 mm. long and 0.04 mm. in diameter.

Cyanuric triazide is insoluble in water and slightly soluble in cold ethyl alcohol, but it is soluble in acetone, benzene, chloroform, ether, and hot alcohol. It melts at 94° C., and there is decomposition when heated above 100° C. In the molten state it is very sensitive to friction. If heated slowly, it may entirely decompose without detonation, but detonates quickly by flame or sudden heating. The small crystals are more sensitive to impact and friction than mercury fulminate and have detonated when being pressed in a detonator capsule. The large crystals, as may be obtained from fusion or recrystallization, have detonated when broken by a rubber policeman.

Cyanuric triazide is a very efficient detonating agent, but is too sensitive to handle safely in large quantities. It is especially sensitive in the form of large crystals such as may be formed from fusion or recrystallization. It is non-poisonous, but the materials used in its manufacture are irritating and poisonous. Further details are given in Serial 2513, of the bureau.

* Communicated by the Director.

FORMS OF SULPHUR IN STEAMED BLAST-FURNACE COKE.

By John H. Thompson.

RECENT studies at the Pittsburgh Experiment Station of the Bureau of Mines have revealed some interesting facts as to the probable behavior of steamed coke in the blast furnace. Enough small-scale tests were conducted to furnish a check on most of the important deductions, and the conclusions derived therefrom accord with what is already known in regard to the forms of sulphur in coke.

The chief contaminating substances in coke are the free sulphur and the ferrous sulphide. Since these two forms are those which steam most readily attacks, steaming the coke would considerably lessen the contaminating influence of sulphur on the iron. No doubt the removal of these two forms by steam is far greater at the surface of the chunk than at the interior; and since this contamination is a contact phenomenon, this surface removal would be another favorable feature. We should therefore expect steamed coke to give up far less sulphur to the iron than the comparative total sulphur figures would indicate. With a view to checking this point, and also to more nearly duplicate blast furnace conditions, several tests were made on both steamed and unsteamed coke. The coke used contained over 3 per cent. total sulphur. Spongy iron was obtained which contained 0.38 per cent. sulphur, and with the exception of about 5 per cent. of impurities—chiefly carbon—was the same as the sponge iron of the blast furnace. The high-sulphur content made possible a study of the sulphur transfer from the iron into the lime, as well as from the coke into the iron. The same coke was used throughout, the only difference being that in one case it was steamed and in the other unsteamed. This steaming was conducted on chunks of plus ½ inch and minus 1 inch sizes. Neither vacuum nor pressure was used, and the removal was therefore more or less confined to the surface of the chunk.

The results suggest two possible methods for correcting the sulphur trouble in the blast furnace: First, surface sulphur could be removed by some such process as steaming, or hydrogenation; or secondly, it could be prevented from entering the spongy iron at this zone by dipping the coke in some material which would absorb the sulphur more readily than would the iron. Possibly

lime could be used, but whatever the nature of the substance, it should be such that it will not interfere with the proper combustion of the coke at the combustion zone. Further studies along this line would no doubt lead to some interesting discoveries as to the behavior of the sulphur in the blast furnace.

LEACHING NON-SULPHIDE COPPER ORES WITH SULPHUR DIOXIDE.

By Charles E. van Barneveld and Edmund S. Leaver.

THIS bureau has devised a cheap and efficient method for treating the so-called "porphyry" copper ores of the Southwest. These ores generally contain both "sulphide" and "non-sulphide" copper minerals, mixed in such proportions that they can only be satisfactorily treated by a method which will concurrently recover both the sulphide copper and the non-sulphide copper. More than one-half of the copper produced in a recent year in Arizona and New Mexico, amounting in value to $106,000,000, came from the so-called "porphyry" low-grade deposits.

The sulphur dioxide leaching process, developed by the bureau, in coöperation with the Miami Copper Company and the Arizona Copper Company, is suitable for a wide range of the ores above described. The advantages of leaching with sulphur dioxide are as follows: The plant is compact and not expensive; there are no installation difficulties; power requirements are light. Operation is simple and easily controlled; there are no delicate adjustments or critical points. Percolation difficulties common to leaching are entirely avoided. Perfect contact is assured between the finest ore particles and the reagent; thus there is excellent utilization of the reagent, which is very cheap. In consequence the process may be extended to ores with so much acid-soluble gangue that they could be treated at a profit by ordinary sulphur-acid leaching. The process is as applicable on a relatively small as on a large scale, and small-scale operation does not necessitate an undue increase in operating cost. Full details are given in Technical Paper 312.

Glucokinin. J. B. COLLIP, of the University of Alberta (*Jour. Biol. Chem.*, 1923, **56**, 513–543, **57**, 65–78), has discovered a hormone, which he has designated as glucokinin, in the tissues of many plants such as yeast, onion, green leaves of lettuce, wheat and beans,

barley roots and sprouted grain. This hormone is quite similar to insulin, the active principle of the pancreas, since it produces a reduction in the sugar content of the blood when injected into an animal. However, glucokinin acts in a somewhat different manner from insulin; and therefore clinical tests of glucokinin upon diabetic patients have been postponed pending further experiments upon laboratory animals. J. S. H.

Separation and Determination of Potassium and Sodium. G. FREDERICK SMITH, of the University of Illinois (*Jour. Am. Chem. Soc.*, 1923, **45**, 2072–2080), has improved the perchlorate method, eliminating the expensive and inefficient extraction with absolute ethyl alcohol, and substituting normal butyl alcohol as a solvent. The new method depends upon the precipitation of potassium perchlorate from its warm aqueous solution in the presence of sodium perchlorate by the slow addition of a relatively large volume of normal butyl alcohol containing from 0.5 to 1.0 per cent. of perchloric acid dihydrate. The solution is boiled with the precipitate for 30 seconds, then cooled to room temperature and filtered through a Gooch or Monroe crucible. The precipitate is washed on the filter, dried for 30 to 60 minutes at a temperature between 150° and 250° C., and weighed as potassium perchlorate.

The sodium is determined in the filtrate by evaporation of the solvent, conversion of the sodium perchlorate into sodium sulphate, and weighing of the latter compound. The sodium may also be determined by difference, weighing the mixed chlorides of sodium and potassium, and then determining the potassium as its perchlorate. J. S. H.

Color Test for Water-soluble B Vitamine. ALADAR JENDRASSIK, of Johns Hopkins University (*Jour. Biol. Chem.*, 1923, **57**, 129–138), has studied the behavior of solutions of the water-soluble B or antineuritic vitamine with various reagents. The absence of this vitamine from the diet gives rise to beriberi in man and to polyneuritis in birds. The sole known test for its presence has been a biological test carried out on laboratory animals, especially pigeons and chickens. Jendrassik's results indicate that the vitamine is not an amine, a phenol, an amino-acid, a peptone, or a higher protein derivative. A concentrated aqueous solution containing the vitamine reacts with an aqueous solution of ferric ferricyanide in the presence of acetic acid, acts as a reducing agent, and causes the development of a deep blue color and a bright blue precipitate. This reaction is also given by certain ptomaines, alkaloids, and glucosides; however, none of these compounds would be present in the aqueous extract of a wholesome food. Therefore, if the concentrated aqueous extract of a food yield a positive result in this test, it is presumptive evidence of the presence of water-soluble B vitamine. J. S. H.

THE FRANKLIN INSTITUTE.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, September 5, 1923.)

HALL OF THE INSTITUTE,
PHILADELPHIA, September 5, 1923.

MR. W. H. FULWEILER, *in the Chair.*

The following reports were presented for first reading:

No. 2800: Work of William Gaertner in the Design and Manufacture of Scientific Instruments.

No. 2808: Pneumercator.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 12, 1923.)

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BOOK REVIEWS.

GELATIN IN PHOTOGRAPHY. Vol. 1, by S. E. Sheppard, D.Sc. 263 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1923. Price $2.50 net.

Gelatin in several forms has been a familiar substance from a remote period. The comprehensive discussion of the chemistry and technology of gelatin and glue in the recent book by Bogue affords the student of the subject many interesting data, among which is the suggestion that an Egyptian carving about 3000 years old shows the use of glue as an adhesive, but upon this point there may be doubt. In the interpretation of ancient inscriptions and figures the "will to believe" is sometimes allowed too free play. The work now in hand deals, as the title indicates, solely with the application of gelatin to one line, in which, indeed it has become a most important substance. Gelatin plates and films have made dry-plates of great permanency and sensitiveness possible, and to such qualities is due the immense vogue of photography and its many applications to science, art and amusement. Doctor Sheppard gives a very interesting and instructive summary of the history of the application of gelatin in photography. Many photographers are still living who remember the days of collodion negatives and albumin positives, and can make the contrast in the convenience and many-sided qualities of the modern plate with the older forms. Yet the older methods are not wholly useless.

Lantern slides made with wet-plates are of high quality, and the albumin portrait may in skilful hands serve very well. Even plain paper is not without value in some lines of work.

When we seek to determine the first suggestor of gelatin as a carrier of the sensitive material, we meet the same difficulty as in all similar searches. The question is, what constitutes original invention or discovery? In all departments of science, adumbrations are noted, which will by some be regarded as the first step, by others as having no bearing upon the final result. Dr. R. L. Maddox, of England, is usually credited with the invention of the dry-plate yet he did not develop his work to satisfactory commercial condition, and it was left to others to carry further the procedure. Maddox, in 1871, used a gelatin-bromide emulsion. It appears, as is so often the case in science, that the success of the gelatin-bromide emulsion depended on two independent conditions. As early as 1862, two investigators had independently discovered that alkaline pyro development was successful with gelatin plates. Such developer applied to collodion coatings was not successful. A great step in the preparation of the gelatin plates was the discovery of the advantage of removing all the soluble salts from the emulsion. This is in marked contrast to the old collodion process, in which the presence of the excess of silver nitrate was necessary, the image being indeed formed from this nitrate, and not from the decomposition of the silver halide upon which the so-called latent image is formed. Here, again, two independent workers made the discovery. It is not necessary to set forth in further detail the incidents of the history of the modern process. They are set forth in a very satisfactory manner in the book. The history of any such procedure is always of value, both as showing the difficulties of the matter, and as also the direction in which research should be pursued. It is always important to bear in mind that even the most implicitly received statements and doctrines may be erroneous, and it is well to test out older data before proceeding to investigate the unknown. It is worthy of note that the present high development of the film photograph, especially in rapid photography and motion picture work, involves inventive talent and research in several lines not in any way connected with photography. The production of flexible, transparent nitrocellulose film and the invention of powerful illuminants are due to other interests than picture making, but have one of their most extensive uses in such work.

The whole process of making commercial gelatins and the general properties thereof form the subject of one chapter, followed by descriptions of the analytic and constitutional chemistry, and the physical testing of gelatin. A comprehensive bibliography and two good indexes occupy the later pages of the book.

The work is a valuable contribution to a highly important field of applied science. Photography has entered into so many phases of life that anything authoritative about it or the materials used in it will be welcome. Printing has been termed the art preservative of all arts, and photography is rapidly displacing ordinary printing in many fields. Gibbon, in speaking of the destruction of manuscripts at the taking of Constantinople by the Turks in 1453, said that fortunately the "mechanics of a German town had invented

an art that enables literature to defy the ravages of time and barbarism." Photography goes further, for it preserves to us the scenes and incidents of actual life. The Eastman Company is doing most excellent work in its research laboratories and publishing departments.

HENRY LEFFMANN.

CHEMISTRY, INORGANIC AND ORGANIC, WITH EXPERIMENTS. By Charles Loudon Bloxam. Eleventh edition, revised by Arthur G. Bloxam, F.I.C., and S. Judd Lewis, D.Sc., F.I.C. 832 pages, including index, 8vo. Philadelphia, P. Blakiston's Son and Company, 1923. Price $9.

Bloxam's Chemistry appeared first in 1867. Though too large for a student's textbook—a field in which the works of Fownes and Silliman were prominent—Bloxam's book was very serviceable for teachers and was widely approved. The author was a teacher as well as research chemist and produced therefore a manual which was comprehensive. His connection with one of the British military schools gave him special interest in the chemistry of explosives, and the book devoted rather more attention to such subjects than was usual in the manuals of that day. Of course, the subject was then much simpler. Although several of the high nitro-explosives were known, the applications of them were not as wide, and the problems of asphyxiating gases and gas masks have of late years brought chemistry into wide and weighty relations to the nations as well as to certain industries. Bloxam was always somewhat conservative in his attitude to theories in chemistry, and preferred to set before the student a considerable amount of what is commonly known as "practical" chemistry before taking up many of the principles. The present edition follows this plan. Nearly three hundred pages are given, largely to elaborate description of experiments, before the general principles of chemistry are set forth. The aliphatic and cyclic hydrocarbons are considered in the same section, a plan which the editors state has met with approval by some and disfavor with others. The matter is probably of no great importance.

The book contains a large amount of information and has been brought up to date on most points. An exasperating condition is the retention of a considerable amount of very old and quite antiquated matter, which simply serves to occupy valuable space. This criticism applies to the illustrations as well as to the text. Many cuts are used which are from the first edition. One of the most astonishing instances of this lack of elision is on pages 16 and 17, in the discussion of the decomposition of water. It is, indeed, not explained that the ordinary electrolytic experiment with water acidulated with sulphuric acid is really a decomposition of the acid and not of the water, but that perhaps is of minor importance, as the water is affected in the secondary reaction, but the suggestion that Grove's cell be used certainly seems strange. Grove's cell went out of use a half century ago, by the invention of cheaper and better methods, and with platinum at about $3 a gram, it is wholly out of the question. The apparatus shown for obtaining hydrogen and oxygen by acting on dilute sulphuric acid with an electric current is a form that is quite out of date. Even some of the cuts, apparently drawn for the recent editions, are lacking

in contemporaneousness. Such is the sketch on page 30 of an apparatus for distilling water. Such apparatus is not now used either on the large scale or in the analytical laboratory. It seems also a waste of space to give some of the methods of making oxygen that are no longer used.

These antiquated procedures and apparatus detract somewhat from the merit of the book, and certainly, as noted above, occupy space that could be devoted to better uses. The price seems rather high for a volume of this size, but it is excellently printed and a large amount of information is presented in a clear and understandable form. It is certainly a convenient and useful work of reference for teachers and advanced students.

HENRY LEFFMANN.

THE OFFICE OF THE CHIEF OF ENGINEERS OF THE ARMY. By W. Stull Holt. xii-166 pages, 8vo. The Johns Hopkins Press, Baltimore, 1923. Price $1 net.

This is one of the series of publications of the Institute for Government Research, an association of citizens for coöperating with public officials in the scientific study of government with a view of promoting efficiency and economy therein. That there is need for such studies is evidenced everywhere and always. Even in private affairs there is much need of scientific study of methods. The popular idea that all private institutions are well-managed and all public institutions badly managed is not correct. The present work relates to the work of U. S. Army engineers, a corps which has a long history, for the Continental Congress on June 16, 1775, one day before the battle of Bunker Hill was fought, authorized the appointment of certain army engineers, and later authorized General Washington to organize a corps. Several French engineers were appointed under this authority. Army officers have had a great deal to do with public works of a non-military character. The question of internal improvements, especially in the vast districts that were acquired by the Louisiana purchase, and the later extension of the Mexican treaty and the Gadsden purchase, brought complicated problems of river and harbor improvements, and road construction into prominence. A considerable amount of political and economic antagonism arose in and out of Congress. The eastern, well-settled and mostly industrial and commercial sections were opposed to spending money on the internal improvements of the West. The eastern sections wanted high prices for public lands in order to deter emigration of labor, and tariff on manufactures. The western sections wanted low prices for public lands and rather low tariffs. National support for such improvements developed but slowly until the close of the war between the States, when the federal power had greatly increased and the western populations had secured a great influence. The story of these struggles is told in an introductory chapter, and is well worth reading by those who are interested in the progress of the United States towards a "more perfect union," and to a united economic effort. The historical portion occupies nearly half the book. Data on the activities of the corps then follow, after which statistical data are given.

HENRY LEFFMANN.

PHYSICS IN INDUSTRY. Lectures delivered before the Institute of Physics. 39 pages, 8vo. New York, Oxford University Press, American Branch, 1923. Price 85 cents.

This volume contains the text of three lectures, respectively, "Physics and Engineering Science," by Prof. Archibald Barr; "The Physicist in Engineering Science," by Sir James Alfred Ewing, and "The Physicist in Electrical Engineering," by Clifford C. Patterson. These lectures are initiative to a course which the Institute of Physics has decided to offer, both for the purpose of interesting the public in general as to the value of research and pure science in aiding practical applications, and also as a guide to students, suggesting lines of usefulness in their studies. Undoubtedly there has been in most great nations an indifference to the value of abstract research. English-speaking peoples have been probably the greatest offenders in this line. Matters have improved somewhat of late years, largely through the severe lessons taught by the war, but much still remains to be done. It is claimed in the preface of this book that there is work to be done for the industries that only physicists can do. This is true, but the claim must not allow us to overlook the fact that there is also much that the chemist alone can do. It is not difficult to name discoveries that when made have seemed remote from practical value and yet have been the initiative of highly useful inventions. The lectures are a useful contribution to the general propaganda in the cause of greater public support of research.

HENRY LEFFMANN.

THE CHEMICAL ENGINEERING CATALOG. Eighth Annual Edition, 1049 pages, 4to, flexible cover. New York, The Chemical Catalog Company, 1923. Price $10.

Notice was made of the seventh edition in the issue of this JOURNAL in November, 1922. The present issue covers the same ground and is made up in the same way. The method of leasing the volume for a comparatively small sum is still followed, but the book may be purchased outright for the sum noted above. It is the official standard work of reference for chemical engineers, works managers, purchasing agents and many others who are connected with the now extensive development of the chemical industries and especially those that buy equipment and materials for use in chemical processes. The volume is prepared under the supervision of a joint committee of the American Chemical Society, the Society of Chemical Industry and the American Institute of Chemical Engineers, but the members thereof have no financial interest in the work. The book consists in the main in a compendium of many catalogues and is intended to inform the purchaser rather than advertise the wares. The supervising committee takes care that general claims, exaggerated statements and display material are excluded, and endeavors to secure the presentation of precise data, including specific uses or adaptation of the equipment or materials. The extensive development of chemical industries in this country is one of the encouraging conditions, tending as it does to render us independent of other nations, and thus able to "go it alone" if war or other catastrophe occurs. The lesson given during the late war does not seem to have

been fully learned by the American people, who are apparently allowing some of the important key industries, especially that of nitrogen fixation, to lapse.

The preface contains a great deal of information concerning the distribution of the work. By furnishing to all firms that carry space a printed list giving the names and addresses of those to whom the book is distributed the value of the compilation is greatly increased. The book is really a wonderful compilation. It is, of course, abundantly illustrated, and being printed on fine paper with clear type and with excellent taste in the display portions, it constitutes a most interesting demonstration of the high degree of efficiency and extensive specialization that the mechanical and chemical interests have undergone. The binding is flexible and permits the book to lie open flat at any page.

HENRY LEFFMANN.

LE MAZOUT. Par E. Davin. 96 pages, 12mo. Paris, A. D. Cillard, editeur, 1923. Price 22 Francs.

Mazout is a Russian word meaning heavy petroleum, that is, fuel-oil. Why such a barbarous term should be introduced into science is difficult to understand, but it seems to have been adopted by French engineers. The pamphlet contains much information on the nature, testing and uses of fuel-oil. The subject is one of great and growing importance, and has, indeed, become one of the most critical problems in international relations. The constantly increasing price of coal and liability of the industry to interruption from strikes have turned the attention of all active nations to the substitution of oil for solid fuel. The saving of labor is immense. In a recent account of the installation of a sea-water distillation apparatus in Chile, it was stated that the substitution of oil for coal enabled the operation to be carried on with two men where eight had been needed when coal was used.

Power engineers of all types will be much interested in this pamphlet, both theoretical and practical data being included. The author states that the first use of petroleum in boiler-firing was by a Russian engineer, Spakowski, in 1867. This was probably the use in locomotives and steamers in the Baku region, where the Russian heavy oil is obtained. Considerable space is given to the recently suggested, so-called "colloidal," fuels, that is, heavy combustible oils containing suspensions of finely powdered solid fuels. Notes of experiments in this field are given from American sources. A U. S. destroyer was fired by a mixture of 31 per cent. of Pocahontas coal and the fuel-oil commonly used in the U. S. Marine. A small quantity of an emulsifying agent had been added to maintain the mixture. There seems to be great promise of useful, economical results along this line.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 166, The Aerodynamic Plane Table. By A. F. Zahm. 11 pages, illustrations, quarto. Washington, Government Printing Office, 1923.

For the accurate and expeditious geometrical measurement of models in an aerodynamic laboratory, and for miscellaneous truing operations, there is frequent need for a specially equipped plane table. For example, one may

have to measure truly to 0.001 inch the offsets of an airfoil at many parts of its surface. Or the offsets of a strut, airship hull, or other carefully formed figure may require exact calipering. Again, a complete airplane model may have to be adjusted for correct incidence at all parts of its surfaces or verified in those parts for conformance to specifications. Such work, if but occasional, may be done on a planing or milling machine; but if frequent justifies the provision of a special table. For this reason, it was found desirable in 1918 to make the table described in this report and to equip it with such gauges and measures as the work should require.

Report No. 169, The Effect of Airfoil Thickness and Plan Form on Lateral Control. By H. I. Hoot. 11 pages, illustrations, quarto. Washington, Government Printing Office, 1923.

Tests for the purpose of determining the effectiveness of ailerons were made on six model airfoils in the No. 1 wind tunnel of the National Advisory Committee for Aeronautics. The method consisted in measuring the rolling moments and aileron moments in the ordinary way. In addition to this the wing was allowed to spin freely about an axis in the direction of the air flow and the angular velocity measured.

The results show that the thickness of the airfoil has very little effect on either the rolling moment or the hinge moment, but that the tapering in plan form somewhat decreases the rolling moment and hinge moment, although the resulting efficiency is somewhat higher for the tapered wings. The airfoil tapered in plan form, however, shows practically no falling off in the rolling moment at the critical angle of attack, whereas the wings of rectangular plan form show a marked dropping off in the rolling moment at this point. This indicates that it is possible to obtain good lateral control with small ailerons at low speeds if the plan form is tapered. The rotational speed of the different airfoils is practically the same for all of the sections tested.

PUBLICATIONS RECEIVED.

Chemistry, Inorganic and Organic, with Experiments. By Charles Loudon Bloxam. Eleventh edition, revised by Arthur G. Bloxam, F.I.C., and S. Judd Lewis, D.Sc. 832 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1923. Price $9.

Heat and Energy. By D. R. Pye. Clarendon Science Series. 211 pages, illustrations, 12mo. Oxford, Clarendon Press; New York, Oxford University Press, 1923. Price $1.70.

Gelatin in Photography. Vol. I, by S. E. Sheppard, D.Sc. 263 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1923. Price $2.50.

Biomathematics, being the Principles of Mathematics for Students of Biological Science. By W. M. Feldman. Introduction by Sir William M. Bayliss. 398 pages, illustrations, 12mo. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1923.

Mineral Valuation. By Henry Louis. 281 pages, illustrations, 8vo. London, Charles Griffin and Company; Philadelphia, J. B. Lippincott Company, 1923.

Institute for Government Research. Service Monographs of the United States Government, No. 27. The Office of the Chief of Engineers of the Army. Its non-military history, activities, and organization, by W. Stull Holt. 166 pages, 8vo. Baltimore, The Johns Hopkins Press, 1923. Price $1.

La Tension de Vapeur des Mélanges de Liquides. L'Azéotropisme par Maurice Lecat. Première partie, Données experimentales. Bibliographie. 319 pages, 8vo. Gand, Belgium, Ad. Hoste, 1918.

Carènes de Formes Nuisibles ou Favorables a leurs Grandes Vitesses; et Résistances de l'Eau a leur Translation. Par M. le vice-amiral F. E. Fournier. 27 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1923. Price 3 Francs 50.

Probité Scientifique. Par Maurice Lecat. 24 pages, 8vo. Louvain, Author, 1923.

Bibliographie des Séries Trigonométriques. Avec une appendice sur le calcul des variations par Maurice Lecat. 169 pages, 8vo. Louvain, Author, 1921.

Bibliographie du Calcul des Variations Depuis les Origines Jusqu'à 1913. Par Maurice Lecat. 2 vols., 8vo. Gand, Belgium, Ad. Hoste, 1913, 1916. Price 8 Francs 50.

Physics in Industry. Lectures delivered before the Institute of Physics by Archibald Barr, Sir James Alfred Ewing, and Clifford C. Patterson, with a foreword by Sir J. J. Thomson. 59 pages, 8vo. London, Henry Frowde, 1923. Price 85 cents.

Le Mazout. Par E. Davin. 96 pages, illustrations, 12mo. Paris, A. D. Cillard, 1923. Price 22 Francs.

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Melting Point of Ice on the Absolute Scale.—A recalculation of the melting point of ice on the absolute temperature scale by LEIGHTON B. SMITH and ROBERT S. TAYLOR, of the Massachusetts Institute of Technology (*Jour. Am. Chem. Soc.*, 1923, **45**, 2124–2128), gives the value 273.13°. J. S. H.

CURRENT TOPICS.

A Radio-acoustic Method of Locating Positions at Sea. A. B. Wood and H. E. Browne. (*Proc. Phys. Soc.*, April 15, 1923.)—A charge of 9 ounces of explosive is fired in water and at the same time a dash is sent by wireless telegraphy. The two waves arrive at different times at four stations in the sea of which the location is known. The speed of the wireless wave is so great that it may be regarded as arriving simultaneously at all points within a radius of a few hundred miles. The arrival of the explosion wave is noted by a hydrophone and the resulting current is transmitted to one string of an Einthoven galvanometer on shore. This instrument has three additional strings for as many more hydrophones, a string for a time-recording device and still another for the recording of the arrival of the dash. The speed of the wave in water is accurately known in its dependence on temperature and salinity. The product of this speed by the number of seconds required for the wave to travel to the hydrophone from its source gives the distance of the source from the hydrophone. The source is, therefore, located anywhere on a circle drawn around the hydrophone as a centre with this product as a radius. From the data derived from a second hydrophone the source will be located on a second circle. It must in consequence be at one of the two points where two circles in general intersect. The third hydrophone fixes definitely the position of the source. The location of a vessel can be furnished to it within ten minutes of the time when request was made for a "fix." In misty weather with heavy seas the locations obtained by this method were more accurate than those got by the navigating officer through the use of ordinary methods. "The R/A method possesses the very great advantage of being equally accurate and reliable, day and night, at all seasons of the year and under all weather conditions—whereas directional W/T locations are often open to doubt, peculiar errors of several degrees in bearing being of frequent occurrence."

G. F. S.

A Supposed Relationship between Sun-spot Frequency and the Potential Gradient of Atmospheric Electricity. C. Chree. (*Proc. Phys. Soc.*, April 15, 1923.)—From a consideration of the observations made at the Ebro Observatory, Spain, Dr. L. A. Bauer has drawn the conclusion "that both the range of the diurnal inequality of atmospheric electricity potential gradient and the mean value of the element for the year increase and diminish with sun-spot frequency." At Kew a Kelvin water-dropping electrograph has been in operation since 1862. An examination of the data furnished by it

in a general way is confirmatory of Doctor Bauer's conclusion yet "one would like to feel quite sure that there is no reasonable explanation of a more local nature than sun spots for the phenomena."

"It may be pointed out that if the mean annual gradient of potential waxes and wanes all over the earth with sun-spot frequency, so also must the earth's total negative charge."

At the close of the paper Dr. D. Owen asked whether the electric fields observed extended only between the surface (of the earth) and the upper atmosphere. The speaker replied, "Observations of potential gradient made from balloons in fine weather have shown a rapid decline in the gradient with height above the ground. The inference is that the lower layers of the atmosphere contain a charge opposite in sign to that of the earth's surface. Balloon observations have not, so far as I know, ever shown an actual reduction to zero in the potential gradient. But the natural inference from the somewhat limited data available is that under normal conditions the lowest 10 km. of the atmosphere contain a charge opposite in sign to that on the earth's surface and making at least a close approach to equality with it." G. F. S.

Effect of Germanium Dioxide upon the Blood.—Germanium dioxide has been used in the treatment of certain types of anæmia. JOHN HUGHES MÜLLER and MIRIAM STEWART ISZARD, of the University of Pennsylvania (*Jour. Metabolic Research*, 1923, 3, 181–199), have made an exhaustive study of the effect of germanium dioxide upon the blood. A concentration of 0.014 per cent. of germanium dioxide represents the approximate saturation capacity of the blood for that compound; therefore, the maximum effect is produced in a person of average weight by administration of 0.8 to 1.0 gram of the dioxide. In venous blood, the germanium is localized in the cellular elements rather than in the plasma. In oxygenated or arterial blood, the germanium occurs in greater quantity in the plasma than in the cells; this blood yields an absorption spectrum which does not differ noticeably from that of normal oxyhemoglobin. However, reduced or venous blood containing germanium yields a characteristic absorption spectrum, which appears upon exposure of the oxygenated blood to the action of reduced pressure, carbon dioxide, or certain oxygen-consuming bacteria. Apparently when germanium dioxide is injected into the system, it is reduced in the tissues to germanous oxide which then combines with the hemoglobin of the red blood-cells and appears in that form in the venous blood. On oxygenation of the blood in the lungs, the germanous oxide is oxidized to the dioxide, which is non-volatile and remains in solution in the plasma or liquid portion of the blood. In this form, it returns to the tissues with the arterial blood. Here reduction again occurs; and the entire cycle is repeated. Hence the germanium derivatives may function as oxygen carriers in the blood

stream. Germanium dioxide also exerts a specific erythropoietic action, that is, causes the animal organism to produce erythrocytes or red blood-corpuscles. J. S. H.

The Mechanism of Soaring and the Morphology of Soaring Birds. C. NORDMANN. (*Comptes Rendus*, Aug. 20, 1923.)—In soaring both propulsion and sustentation need to be explained. "It is easy to show by elementary considerations that by arranging its wings properly the bird finds in the wind a component urging it forward. . . . The problem of sustentation in soaring is, on the other hand, still in suspense." The theory, proposed by Mouillard and developed by Langley, that the bird is kept up by utilizing each gust in a series, is discussed and rejected as unsatisfactory. The author produces the following theory for consideration, that the angle of attack of the bird is not always positive, as has hitherto been assumed. It is positive when the gust causes a motion of the bird into the wind and negative when the wind overtakes the bird. In both cases there would be an upward component, supporting the weight of the bird.

This at once makes clear certain actions of soaring birds that could not be explained by the former theory such as the fact that they progress continuously upward both in straight and in curved flight. Further, an examination of the structure of soaring birds discloses that it is just such as would be needed did they have the ability to make the same adjustment of angle to a wind coming from the rear as to a wind from the front. Furthermore the location of the centre of gravity of the bird and the position of the terminal pinions of the wing in soaring cause the adjustment of the angle of attack to be automatic. G. F. S.

Work of the Physikalisch-Technische Reichsanstalt for 1922. (*Zeit. f. Instrumentenk.*, March, 1923.)—The President, Professor Warburg, retired in March, 1922, and was succeeded by Professor Nernst.

Early in the report is found a statement of the difficulty experienced in getting magazines. Only in America was it possible to arrange exchanges with satisfaction. The *Philosophical Magazine* was furnished gratis by a professor in Upsala. The *Electrician* could not be had at all on account of the high price as expressed in worthless currency.

To show the high value of the work performed nothing is needed beyond an enumeration of the subjects of investigation, but this in itself would fill too large a space. Let these suffice the Balmer series of hydrogen, examination of radioactive preparations, the melting point of platinum, testing of 8062 non-clinical mercury thermometers, diffusion of helium through glass, metallic crystals, high frequency telephone, photo-chemistry. G. F. S.

The Electrification Produced by the Pulverization of Aqueous Solutions. J. J. NOLAN and REV. H. V. GILL. (*Phil. Mag.*, Aug., 1923.)—"The liquid is sprayed in a horizontal direction from a metal sprayer driven by air under pressure. The drops fall into an insulated metal tray. This, together with the sprayer itself, which is also insulated, is connected to a Dolezalek electrometer which measures the charge. The electrometer therefore records the charge on the water due to the electrical separation at the water-air surface, the charge of the opposite sign being carried off in the air as an excess of ions of one sign." In a previous paper one of the authors examined the electrical charges produced when water of differing degrees of purity was broken into smaller portions in contact with air. "Considered in connection with Simpson's theory of thunderstorm electricity, the magnitudes of charge observed showed that if a moderate degree of purity were attributed to the rain-drops in a thunderstorm, the breaking of the drops in the manner supposed by Simpson would produce sufficient separation of electricity to account for the observed effects."

The method of the present paper was to vary the concentration of the solutions tested while the pressure of the sprayer and consequently the degree of pulverization was kept constant. "The substances most likely to be present in rain in the free atmosphere are nitrates, sodium chloride from evaporated sea spray, hydrogen peroxide and dissolved gases such as ammonia, carbon dioxide, oxygen, and nitrogen. It may be stated at once that, judging from their effect when added to distilled water, these substances, with the single exception of sodium chloride, will not seriously affect the charge developed when a rain-drop is broken." When NH_3 is present to the amount of .5 gram per litre of water, that is, in a proportion about 1000 times as great as that occurring in country districts, then the electrical charge manifesting itself drops to 1 per cent. of that of pure water. "If Simpson's theory of thunderstorms is correct, it would seem that if ammonia could be introduced into the thunder-cloud in sufficient quantity to form with the rain-drops a solution of this strength (or even one-tenth of this strength) the development of a thunderstorm would be seriously impeded. This is an experiment which is perhaps within the bounds of possibility."

It was only after long search that the authors succeeded in obtaining negative charges from the breaking up of solutions of sodium chloride. Finally such charges were got from a high degree of pulverization. The general conclusions of the paper are these:

(1) "Inorganic salts in increasing concentration diminish the positive charge when water is broken."

(2) "Non-electrolytes do not affect the development of charge."

(3) "A group of substances shown by Lewis to give abnormal adsorption effects have a great influence on the sign and magnitude of the charge at very low concentrations." G. F. S.

On the Changes in Iron and Steel at Temperatures Below 280° C. F. C. THOMPSON and EDWIN WHITEHEAD. (*Proc. Roy. Soc.*, A 218.)—The change of electrical resistance produced by a rise of temperature was studied for pure iron, mild steel, high carbon steel and white pig iron. When the change per degree is plotted against temperature a series of maxima and minima discloses itself, the first of which is not much above room temperature. The general form of the curves is that of a succession of written u's. Between 20° and 260° C. all but the pig iron show nine cusps. It has ten. An examination of the thermoelectric power confirms the evidence previously obtained. "Iron shows abnormalities of the rates of increase of electrical resistance and electrical potential against platinum at well-marked temperatures. Below 280° C. these temperatures are 55, 100, 120, 140, 220 and 245° C. Of these those at 120 and 220° C. are the most important. It is difficult to believe that these can be of the nature of allotropic changes, and for the time the explanation must be taken as unknown. Under the same conditions carbide of iron possesses two well-marked points at 160 and 200° C." G. F. S.

Insulin.—The pancreas produces two secretions, an external and an internal. The external secretion is a digestive fluid and passes through a duct into the intestine where it exerts a digestive action on starches, fats and proteins. The internal secretion is insulin; it is produced by the regions of the pancreas known as the islands of Langerhans, passes directly into the blood-stream, and governs the metabolism of the sugar which has been absorbed from the intestine. Diabetes mellitus is due to the failure of the islands of Langerhans to produce insulin. The sugar content of the blood then becomes excessively high, and sugar is present in the urine. Banting, of the University of Toronto, has succeeded in preparing insulin from the pancreas of slaughter-house animals by a process of alcoholic extraction. The insulin is administered by injection, and has been used with marked success in the treatment of diabetes. However, treatment must be continued indefinitely. Great care must be exercised with respect to the dosage, especially to avoid an overdose. Therefore its use should be under the control of a physician. A summary of our present knowledge of insulin is given by R. M. WILSON (*Science Progress*, 1923, **17**, 585–587). J. S. H.

The Crystal Structure of Various Heusler Alloys by the Use of X-rays. J. F. T. YOUNG. (*Phil. Mag.*, Aug., 1923.)—At present, in spite of the fine work of Langevin, Pierre Weiss, Gans and the Comptons, there is no theory of magnetism that is entirely satisfactory and the nature of the ultimate magnetic particle remains a matter of debate. This paper presents the results of an investigation of the Heusler alloys, discovered in 1903. They contain the two paramag-

netic metals, manganese and aluminum, and the diamagnetic metal, copper, and some of them have magnetic qualities similar to those of soft iron. Since such alloys are quite strongly magnetic, though built up of metals, no one of which is anything but weakly paramagnetic or diamagnetic, they might well furnish some clue to the type of arrangement that causes magnetic properties. With this in view "a systematic crystal analysis of definite Heusler alloys in different conditions was undertaken, using X-ray methods." In no case did the photographs of the diffraction patterns of the two alloys investigated show any trace of the lines characteristic of the three constituent metals. The interpretation of the figures led to attributing to the magnetically weaker the crystal structure of a face-centred cube and to the stronger that of a combination of this same face-centred cube with a body-centred cube. Just this same difference of structure had been previously found to exist between a nickel steel in its non-magnetic state and in its magnetic state. "The superposition of a magnetic field of 3500 gauss did not alter the crystal form of the alloys or make any noticeable change in the relative intensities of reflection from the different crystal planes, indicating no change in orientation of the crystal unit." G. F. S.

Stability of Sodium Thiosulphate Solutions.—Since standard solutions of sodium thiosulphate are extensively used in volumetric analysis, the stability of these solutions is a matter of great importance. MARTIN KILPATRICK, JR., and MARY L. KILPATRICK, of Vassar College (*Jour. Am. Chem. Soc.*, 1923, **45**, 2132–2135), have studied the stability of several one-hundredth normal solutions of this salt over a period of eight months. Freshly boiled redistilled water yielded a solution which was more permanent than those prepared with laboratory distilled water, ordinary redistilled water, and redistilled water through which air free from carbon dioxide had been bubbled. The stability of the solution was influenced but little by carbon dioxide, oxygen, and dilute sodium hydroxide. Decomposition of the solution was caused by the action of bacteria.

J. S. H.

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